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HISTORICAL SUMMARY OF ACTIVITIES IN THE
UC-FAA FOG CHAMBER

Don O. Horning, et al

California University

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August 1971

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**HISTORICAL SUMMARY OF
ACTIVITIES IN THE UC-FAA FOG CHAMBER
UNDER CONTRACT ARDS-434**

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FINAL REPORT

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16. Abstract A historical summary of the activities and abstracts of reports developed by use of the UC-FAA Fog Chamber. The 1000 ft long building which constitutes the chamber is described in detail. The 10th scale runway lighting system and its control are described. The fog producing system is explained as well as the means for uniform fog density control. Information on basic instrumentation is included.			
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Mr. Alvah Miller	Assistant Development Engineer
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FINAL REPORT

HISTORICAL SUMMARY OF
ACTIVITIES IN THE UC-FAA FOG CHAMBER
UNDER CONTRACT ARDS-434

Compendium of Work Performed, Including Abstracts of Reports

Contract ARDS-434 was initiated October 30, 1961. In the subsequent 10 years a total of 42 amendments have been used to provide work statements and modify the terms of the contract. A list of these amendments and modifications is as follows:

Amend- ment	Effective Date	Amendment Action
1	8/ 1/62	Extended termination date to Nov. 15, 1962 without additional cost and provides that FAA would supply open type pancake airport lights.
2	7/17/62	Added \$44,500 to contract "Limitation of Cost" for continuation of work under Amendment #1.
3	11/16/62	Extends termination date from November 15, 1962 to March 15, 1963.
4	3/16/63	Added new requirements: 1) to test "Cross-pip" lighting in combination with runway centerline lighting, 2) test inter-relation between component parts of an integrated approach and runway lighting system. Added \$63,100 to contract "Limitation of Cost", and changes termination date to Dec. 31, 1963.
5	1/ 1/64	Provides a specific test program for determination of the effectiveness of all elements of an airport lighting system under low visibility conditions. Tests to include information on the effectiveness of the centerline lighting as a guide in low visibility conditions.
6	6/28/63	Added \$55,000 to contract "Limitations of Cost". Tests on the approach section of the airport lighting system.
7	7/ 1/63	Added \$45,000 to the contract "Limitation of Cost". Modified period of performance to Dec. 31, 1963 for Fog Chamber maintenance.
8	1/ 1/64	Adds \$54,000 to the contract "Limitation of Cost" for maintenance and extends termination date to July 31, 1964.
9	8/ 1/64	Authorizes use of the Fog Chamber in connection with a State of California sponsored program of Fog Accident Prevention at a cost of \$28.00/hr.

<u>Amend- ment</u>	<u>Effective Date</u>	<u>Amendment Action</u>
10	8/ 1/64	Provides funding in the amount of \$34,000 for a 200 ft extension to the Fog Chamber facility. Contract date changed to Oct. 31, 1964.
11	11/ 1/64	Added \$84,000 to contract "Limitation of Cost" and extends termination date to July 31, 1965.
12	10/23/64	Permits the use of the FAA Fog Chamber for other research programs with approval from FAA.
13	8/ 1/65	Extends completion date of additional 200 ft funded in Modification #10 to Jan. 8, 1965.
14	5/ 1/65	Extends termination date of Modification #6 on approach lighting system study to June 1, 1965 without additional funds.
15	4/19/65	Provides for testing 50 ft spacing of centerline lights under specified conditions at two intensities, 2000 cp and 5000 cp.
16	7/ 9/65	Continuation of work under Amendment #5. Increases contract "Limits of Cost" by \$173,000 and extends termination date to May 31, 1966.
17	7/19/65	Provides for study of Backscattered Light on the detectability of light signals seen through a light fog.
18	6/ 2/65	Increase in contract "Limits of Cost" for Fog Chamber maintenance by \$86,000 and the extended period of performance to July 31, 1966.
19	10/14/65	Transferred government furnished property from FAA/BRD-4 to ARDS-434.
20	8/ 1/66	Extends termination date to August 31, 1966.
21	9/ 1/66	Extends termination date to Sept. 30, 1966.
22	10/ 1/66	Provides for study of: 1) ICAO Lighting Pattern for approach lights; 2) Minimum requirements for visual guidance with emphasis on the effect of maintenance, outages, and partial failures of the lighting system. 3) Study of an improved visual approach slope indicator system. 4) Supersonic Transport and other new aircraft visibility studies. The contract "Limits of Cost" were increased by \$300,000 and the period of performance extended to September 1969.
23	3/21/67	Lists revised overhead rates.

<u>Amend- Effective ment</u>	<u>Date</u>	<u>Amendment Action</u>
24	12/15/66	Transferred payment office from NAFEC at Atlantic City to the Federal Aviation Agency, Washington, D. C.
25	6/15/67	Increase the contract "Limits of Cost" by \$34,800 to cover the cost of purchase of compressors.
26	10/ 1/67	Extended the contract for maintenance of the Fog Chamber from Sept. 30, 1967 to Sept. 30, 1968 and increased the contract "Limits of Cost" by \$75,000.
27	4/15/68	Increased the cost of use of the Fog Chamber from \$28/hr to \$80/hr and established need for FAA approval for use.
28	10/ 1/68	Increased the contract "Limits of Cost" by \$50,000 for Fog Chamber maintenance and extended the period of performance from Sept. 30, 1968 to June 30, 1969.
29	7/ 1/69	Established the Runway Marking Studies. Increased the contract "Limit of Cost" by \$145,000 and extends the termination date to Nov. 30, 1970.
30	12/ 1/70	Extends termination date of Fog Chamber maintenance from June 30, 1969 to Sept. 30, 1969.
31	10/ 1/69	Increases the contract "Limits of Cost" by \$75,000 for Fog Chamber maintenance and extends termination of contract to Sept. 30, 1970.
32	4/18/69	Adjusts overhead rate to 45% for On-Campus and 26% for Off-Campus work.
33	8/15/69	Establishes the study entitled "Investigate Effect of Head-Up Display Illumination on Pilots Ability to See Runway Lighting in Fog." Increases the contract "Limits of Cost" by \$88,200. Period of performance, one year.
34	5/ 1/70	Adds funds for the development of moving picture method of evaluating Runway Outages as described in Modification 22(2). Increases the contract "Limits of Cost" by \$48,700.
35	12/ 1/70	Extends period of performance from Aug. 15, 1970 to Dec. 15, 1970.
36	10/29/70	Adds funds for completion of Head Up Display Study of Modification 33 and extends date of performance from Sept. 30, 1970 to March 31, 1971. The contract "Limits of Cost" increased by \$44,906.
37	1/ 8/71	Adds funds for Phase II of the Head Up Display Study of Modification #33. Increases contract "Limits of Cost" by \$24,500.

<u>Amend- Effective ment</u>	<u>Date</u>	<u>Amendment Action</u>
38	12/16/70	Extends completion date on Article I, Scope of Work, Item P (Modification 22, 29, 34) from November 30, 1970 to March 31, 1971.
39	12/16/70	Extends completion date for Head Up Display Study of Modifications 33, 36 and 37 from Dec. 15, 1970 to March 31, 1971.
40	3/19/71	Adds funds for Head Up Display Study by increasing contract "Limits of Cost" by \$4,400.
41	4/ 1/70	Extends completion date with no increase in funds from March 31, 1971 to June 30, 1971.
42	7/ 1/71	Extends completion date with no increase in funds from June 30, 1971 to Aug. 31, 1971.

The above amendments and modifications have had a total aggregate contract cost of \$1,708,706.00. Expenditures of the funds, rounded off to even thousands, were divided into the following categories:

General Assistance (Salaries)	\$805,000.00
Employee Benefits.	64,000.00
Supplies and Expense	328,000.00
Equipment and Facilities	179,000.00
Overhead.	<u>332,000.00</u>
Total.	\$1,708,000.00

Various reports and submissions of material have been sent to FAA during the performance of the contract. A list of these with an appropriate abstract of each is as follows:

1. Interim Report on Preliminary Investigation of Intensities and Spacings of Runway Center-line Lights. Authors: H. G. Paula, D. M. Finch, and R. Horonjeff. Special ITTE Report, November 1962.

The primary purpose of the study was to determine the relative effectiveness of runway center-line lights with the emphasis being placed on intensity versus spacing. Photographs of the various light intensities and spacings were made at fixed points on the approach path with visibility ranges of 1200 and 2600 feet. Also, brightness measurements were made with a Pritchard Spectra Telephotometer. Several pilots also observed the lights under the 1200 foot visibility range. The conclusions drawn from the preliminary tests were:

- 1) In daytime the intensity must be much higher than at night and under 1200' VR light intensities in excess of 200 cp at 25 ft spacing may be needed;
- 2) At night indications are that lights with 10 cp on 12-1/2 ft centers;
- 3) Better definition is provided by closely spaced lights; and
- 4) The intensity of the approach lights in the vicinity of the threshold have a distinct effect on the quality of information provided by the runway and touchdown zone lighting.

2. Interim Report No. 2, An Investigation of Three Combinations of Intensities and Spacings of the U. S. National Standard for Runway Touchdown Zone and Centerline Lighting. Authors: H. G. Paula, G. Ahlborn, W. E. Gillfillan, R. Horonjeff and D. M. Finch. Special ITTE Report. May 1963.
-

This was a continuation of the initial study of centerline light intensity and spacing requirements. 16 pilots participated in the evaluation. Brightness distribution graphs were plotted for all conditions studied. Three conditions, or light patterns, were used in 1200 ft visual range. The conclusions reached were:

- 1) That the highest apparent intensity of touchdown zone and centerline lighting was not high enough for daylight fog in 1200 ft visibility range in bright sunshine; and
- 2) In all cases, both day and night, prior to reaching the threshold, the centerline lights did not stand out as clearly as the touchdown zone lights. Additional tests at much higher light intensities were recommended.

3. Interim Report No. 3. A Comparative Evaluation of 3:3:3, 3:2:1, and 7:3:1 Patterns of Runway Touchdown Zone Lighting at Different Intensities and Spacings. Author: H. G. Paula. Special ITTE Report. July 1963.
-

In the 3:2:1 pattern, the light barrettes constituting the narrow gage were made up of 3 lights for the first 1000 ft after threshold, 2 lights for the second 1000 ft and one light for the third 1000 ft. The intensities were 7500 cp at 100 ft for the touchdown zone and 200 cp at 25 ft for the centerline for the high, 200 cp at 25 ft for the touchdown zone and 60 cp at 25 ft for the centerline for the low, and a combination of 7500 cp at 100 ft for the first 1000 ft of the touchdown zone after threshold and 200 cp for the second and third 1000 ft with 200 cp at 25 ft for the centerline. The 7:3:1 pattern consisted of lights spaced 25 ft apart across the runway with the center three lights spaced 12-1/2 ft apart longitudinally along the runway. The seven light system extended for 1500 ft from the threshold, the three center lights extended for the second 1500 ft, and the centerline lights extended for another 1000 ft. All lights were set for 10 cp. This configuration was only evaluated at night in light fogs. The 3:3:3 pattern consists of 3 lights placed 30 ft from the centerline spaced every 100 ft. The latter by concensus of 15 pilots was preferred for both daytime and nighttime visibility ranges of 2600 ft and 1200 ft. The intensity for daylight use, even at 7500 cp, was considered too low for good guidance. The low intensity was unacceptable under most conditions.

4. Interim Report No. 4. A Preliminary Evaluation of Effectiveness of Runway Marking in Fog with Bright Sunshine Overhead. Authors: D. M. Finch and R. Horonjeff. Special ITTE Report. August 1963.
-

The use of lights as a means of providing runway position in bright sunlight conditions is limited. In this study, all-weather runway marking as required by FAA Technical Standard Order N106, dated Oct. 5, 1960, was painted on the runway in the Fog Chamber and observations by a small number of pilots were made in daytime fog with bright sunshine overhead. The conclusions reached were that such runway markings were of considerable aid to the pilots for landings and takeoffs and were superior to lights alone. The combination of touchdown zone and centerline lights and marking was an improvement over markings alone, but to obtain the maximum benefit from the system, the effective intensity of the centerline lights, as well as the threshold, must be increased.

5. Interim Report No. 5. An Investigation of Intensities for the U. S. National Standard Runway Touchdown Zone and Centerline Lighting in a Visual Range of 1200 Feet. Authors: D. M. Finch, R. Horonjeff, H. G. Paula, and G. Ahlborn. Special ITTE Report. January 1964.

This report contains the results of an investigation in the Fog Chamber concerned primarily with the establishment of the intensities in a visual range of 1200 ft of the runway touchdown zone and runway centerline lights for the spacing and configuration specified in AGA-NS13, the "U.S. National Standard for Runway Touchdown Zone Lighting and Runway Centerline Systems." In addition, a brief evaluation of the inner 1000 ft of approach lights was conducted.

The intensities were evaluated primarily by the pilots observing the lights, measurements of brightness, and analysis of photographs. A total of 36 transport pilots from the major domestic and international carriers, the Flight Standards Service of the Federal Aviation Agency, and the U. S. Air Force participated in the tests. The tests were conducted during the day and night.

Findings considered significant are:

- 1) During the day, background brightness has a profound influence on required intensity. The higher the background brightness, the higher must be the intensity to provide adequate guidance.
- 2) When the background brightness is high, the gains in range that can be achieved, even by a large increase in intensity, are relatively small (although there is a significant improvement in the clarity of lights). Background brightness is therefore an important parameter in the design of a lighting system.
- 3) For conditions as provided in the Fog Chamber in this test program, centerline lights should be at a minimum of 2000 cp at 25-ft spacing along the full length of the runway and the touchdown zone lights should be at a minimum of 7500 cp at 100-ft spacing.
- 4) The distribution of intensity from each lighting fixture is extremely important. The intensity (candlepower) viewed by the pilot should be approximately equal for all lights within his field of view. This is not realized if a fixture has too narrow a distribution in either the vertical or horizontal planes. The geometry of the pilot's field of view is such that a fixture should provide a uniform intensity through an angle extending to 13-15 degrees above horizontal. This is especially important in dense fog because the pilot must depend for guidance primarily on the lights near the aircraft.
- 5) Visual guidance provided by runway touchdown zone and centerline lights can be improved with the photometric distribution suggested in this report. The feasibility of accomplishing this in the field should be investigated.
- 6) For threshold lights, it is suggested that the intensity be increased to provide no less than 5000 cp in green light and that the intensity be distributed as suggested in this report.
- 7) Modification of the inner 1000 ft of approach lights as described in this report was considered desirable by the pilot observers, especially during the day. The modification consists of placing an additional white-light barrette midway between the threshold and the red-light terminating bar and making the inner 4-light segment of the terminating bar white instead of red.

6. Evaluation of Runway Lighting Systems for Effectiveness in Dense Fog. Authors: D. M. Finch, R. Horonjeff and H. G. Paula. Special ITTE Report. January 1966. SRDS Report No. 65-58.

The test facilities and methods are described, the test results are presented, and some of the influencing factors, such as background brightness and cockpit cutoff angle, are discussed. In addition, a number of recommendations are made with regard to intensities and photometric distributions for runway lights, and with respect to changes in the present U. S. standard approach light system.

Evaluations were made with pilot observers, photometric measurements and photographic techniques.

Tests of runway lighting systems in dense fog show that an intensity of 200 to 300 cp, now in general use for centerline lights at U. S. airports, is not high enough for effective guidance in a fog density of 1200-ft visual range, day or night. These tests also indicate that in daytime, with a 1200-ft visual range, runway marking is considerably useful to pilots as a supplement to runway lighting. In addition, on the basis of pilots' reactions, the present U. S. standard pattern (3:3:3) for touchdown-zone and centerline lights was found to be more effective than either of two other patterns (3:2:1 and 7:3:1) evaluated. Pilots also preferred a modified version of the present U. S. standard approach-light system.

7. Evaluation of ICAO Visual Aid Panel Approach Lighting Patterns. Authors: D. M. Finch, R. Horonjeff, and H. G. Paula. Special ITTE Report. February 1966. FAA Report No. RD-65-104.

Nine different patterns for the last 1000 feet of approach lights before runway threshold, including two European and seven U. S. configurations, were evaluated on a reduced scale in the Fog Chamber by tests in daytime and nighttime fog (1200-ft visual range). The tests consisted of observations by 12 pilots. While some of the approach light patterns served better than others, none was clearly outstanding. Therefore, no clear choice could be made for overall effectiveness. Certain features seem desirable in an approach light pattern. These are:

- 1) A well defined centerline without excessive number of lights;
- 2) Distinctive and easily identified marker lights at the 1000 ft and 500 ft distance before threshold;
- 3) No lighting elements so close to the threshold that they tend to visually break up the continuity of the green threshold lights, and
- 4) As simple a configuration of lights as possible.

8. Photometric Detection Contrast of Airport Lighting in Decreased Visibility. Authors: D. M. Finch, R. Horonjeff, and H. G. Paula. Special ITTE Report. August 1966. FAA Report No. RD-66-46.

A photometric method is described for determining the visibility of airport runway lights under various conditions of visual range and background brightness. The method is based on measurement of a defined quantity, C_d , called photometer detection contrast, and depends on the correlation of this quantity with subjective visibility. Use of the photometric method is illustrated by tests conducted in the FAA Fog Chamber. Values of C_d were calculated from luminance scans of runway lights in daytime and nighttime visual ranges of 1600, 1200, and

800 ft. Maximum visibility distances for the lights were then determined by assuming a trial value of .05 as the minimum usable C_d for subjective visibility under the various fog conditions. An automatic scanner mechanism used with a telephotometer for the efficient acquisition of the luminance data is also described.

The photometric method of detecting contrast has the following advantages:

- 1) Provides a means of collecting test data that is much more efficient and economical than the use of pilot observers;
- 2) The objective data so collected does not display the vagaries often encountered in subjective determinations;
- 3) The photometric data, once obtained, remain useful for making runway lighting evaluations even though subsequent work requires changes in the criteria for effectiveness.

9. Effect of Landing-Light Backscatter on Target Visibility in Fog. Authors: D. M. Finch, E. C. Curwen, and L. E. King. Special ITTE Report. September 1966. FAA Report No. RD-66-60.

Tests were conducted in the FAA Fog Chamber to determine if backscatter from aircraft landing lights in visual ranges of 3 miles, 2600 ft and 1200 ft would interfere with an observer's ability to see a set of amber target lights at the runway threshold. Results from a total of 518 test observations made by 14 observers indicate substantially no reduction in target-light visibility in visual ranges of 3 miles and 2600 ft. In the 1200 ft visual range, the visibility of the target lights was reduced by an appreciable amount.

10. Effect of Backscatter from Aircraft Beacon Lights on Target Visibility in Fog. Special ITTE Report. November 1966. FAA Report No. RD-66-57.

Tests were performed in the FAA Fog Chamber to determine how the backscatter from aircraft beacon lights (collision-avoidance lights) in a fog of 0.21 per mile transmittance affects an observer's ability to see a set of target lights at a fixed distance equal to the corresponding visual range of 3 miles (approximately 16,000 ft). The tests investigated three white and three red beacon lights, both steady-burning and flashing, with peak intensities from 1200 to 200,000 cp in white and 1200 to 25,000 cp in red. Results from a total of over 10,000 observations, made by 34 observers, show that use of the beacon lights produced no appreciable reduction in target-light visibility except with the highest white-light intensity. There was no apparent difference between the steady-burning and flashing modes of the beacons insofar as target visibility is concerned.

11. Photometer Detection Contrast and Visibility of Runway Lighting in Dense Fog. Authors: D. M. Finch, R. Horonjeff, H. G. Paula. Special ITTE Report. June 1967. FAA Report No. RD-67-33.

Using a previously developed but modified photometric method, the visibility of a runway lighting system was studied under various conditions of visual range and background brightness. The method is based on measurement of a defined quantity, C_d , called photometer detection contrast, and depends on the correlation of this quantity with subjective visibility. All tests were performed in the FAA Fog Chamber at 1/10 scale. Photometric data for the runway lights were obtained in daytime and nighttime visual ranges of 1200, 900, and 700 ft, and maximum visibility distances for various portions of the lighting system were then determined

on the basis of an assumed value of .06 for the minimum usable C_d . Based on the number of lighting elements that would be visible to a pilot under the various test conditions studied, it was concluded that the lighting system would become but marginally effective for visual guidance in a daytime fog of 900 ft visual range and background brightness of about 500-600 fL. The same would hold true for the nighttime fog of 700 ft visual range. In a daytime visual range of 700 ft, the system would no longer provide effective visual guidance.

12. Evaluation of Centerline Lighting Indications for Runway-Distance Remaining and Taxiway Exits. Authors: D. M. Finch, R. Horonjeff, and K. Mellander. Special ITTE Report. June 1967. FAA Report No. RD-67-10.

Tests were conducted in the FAA Fog Chamber to determine the effectiveness of colored centerline lights for indicating runway-distance remaining and for marking high-speed taxiway exits (large-radius turnoffs) under daytime and nighttime visibility conditions down to 700 ft of visual range. The tests consisted of observations by pilots of various lighting patterns under simulated rollout conditions. The results of the tests indicate that red centerline lights can be effectively used for indicating runway-distance remaining, either in combination with white lights or alone, if the intensity of the red lights is high enough to provide adequate guidance under reduced visibility. The test results also indicate that under conditions of 700 ft visual range, adequate identification and guidance for large-radius taxiway turnoffs can be provided by steady-burning green lights along the taxiway centerlines, with a pattern having an equivalent intensity at least that of 1000 cp lights at 12.5 ft spacing in daytime and 500 cp at 12.5 ft at night. Steady-burning taxiway lights were preferred by the pilots over flashing lights by a very wide margin. Taxiway centerline lights having a much wider beam than that specified by the FAA were visible from a point on the runway centerline farther beyond the beginning of the taxiway turnoff than were the specified narrower-beam lights.

13. An Optical System for Improved Visual Approach Slope Indicators (VASI). Authors: D. M. Finch and R. Muldavin. (Submitted in Draft form December 1968.)

The following is an abstract of this unpublished report:

A study of means for improving the performance of existing Visual Approach Slope Indicators (VASI) shows that an optical system using an elliptical reflector, a red-white interference filter and a suitable projection lens would provide considerably higher efficiency and a sharper color transition in the light beam. Tests indicate that such an optical system is feasible for use in a VASI unit and permits the design of a unit that would provide satisfactory performance under various environmental conditions.

14. Runway Marking Studies. Authors: Don O. Horning and K. Mellander. FAA Report No. RD-70-27. August 1970.

To help evaluate the effectiveness of several different runway marking patterns under limited visibility conditions, a set of special composite photographs was prepared simulating a pilot's-eye view of the patterns from various points along the glide path. The set includes three marking patterns (the U.S. Standard, TSO-N10b, and two modified versions thereof) on both asphalt and concrete surfaces, as viewed under daytime visual-range conditions from 2400 ft down to 700 ft. Each of the composite photos consisted of two visual components combined through appropriate processing techniques. One component was made by photographing a 30:1

scale model runway layout in the UC-FAA Fog Chamber under a given set of conditions. The other component was taken from motion picture film showing the inside of a Boeing 707 flight simulator cockpit as viewed from the pilot's-eye position. The contrasts in the original scenes were matched in the photographs by means of suitable photometric controls.

15. Head Up Display Study. Authors: Don O. Horning, D. M. Finch, Karl Mellander and Alvah Miller. Special ITTE Report. Submitted for approval June 1971.

The objective of this study was to develop methods for the objective and subjective evaluation of the Head Up Display concept under low visibility conditions.

To effect this, two separate studies were made: An objective study of the physical parameters associated with the runway lighting system and a representative head up display device. These parameters included transmission reflectance and luminances on the HUDisplay device and luminances of the cockpit interior as well as the external scene. The measurements were made with a Pritchard Telephotometer mounted to scan the entire scene at a 30 minutes of arc interval. Certain limited segments were scanned at a 6 minute interval.

The data from these scans were impressed on magnetic tape and analyzed by computer techniques. The printout revealed areas of high brightness. These were examined in detail for glare sources and the entire scene analyzed for the accommodation level which could be expected by the pilot viewing the same scene.

The conclusions to be drawn from these studies were that under normal operating conditions with the visibility range at 1200 ft day or night, no glare sources were identified and the accommodation levels were reasonable. The combining glass of the representative HUDisplay used did not materially affect the values. Some diminution of glare was experienced, as might be expected by the partially silvered mirror.

The subjective tests were performed by mounting a typical Head Up Display device, the Singer-Librascope L-193, in the cockpit of the "flying" tramway of the Fog Chamber and subjecting experienced pilots to making approaches under limited visibility conditions. Instrumentation provided data on at what point in the approach the pilot was sufficiently well oriented to make the decision to land. Identical runs were made 1) with the pilot using the Head Up Display, and 2) following the present mode when making an instrument approach to have the pilot concentrating on the cockpit instrument display and coming head up when the co-pilot signalled he had lights in view. The first series of these runs indicated a slight improvement in pilot performance using the HUDisplay. However, the sample was small and certain refinements in instrumentation were required to improve the accuracy of the data. A second series of pilots produced more consistent data with the results showing virtually no difference between head up and head down decision points.

All pilots were asked to comment on the experiment and their opinion of the head up concept. The pilots agreed almost unanimously that the experiment as a whole was very adequate in providing them with a high degree of realism, particularly at night for the visibility conditions used, and that the Head Up Display concept had validity in providing them with a sense of confidence in making a decision to land under adverse weather conditions.

The original objectives to develop methods for evaluating the Head Up Display concept, both objectively and subjectively, were successfully met.

16. Development of Filming Technique for Runway Lighting Studies. Authors: D. K. Hamma, D. M. Finch. Special ITTE Report. (Submitted to FAA for Comment on Aug. 1, 1971.)

This report delineates the various techniques developed on this project to provide a motion picture of a simulated approach, touchdown, and rollout under various conditions, day and night, on centerline, offset, and crabbed, in low visibility conditions of 1200 and 700 ft fogs. The method utilizes a compositing of films made in a 707 cockpit training simulator and films made in the FAA Fog Chamber. The result is a simulated moving picture of the flight. The realism is fairly good. Some improvement can be expected as lighting systems used to photograph the cockpit are improved and special techniques are employed to provide realistic transition from wholly instrument flight to the external scene. A step by step procedure is outlined in order that the technique can be employed by other agencies.

In addition to the above reports, several films of the last segment of the approach, touchdown, and rollout of an aircraft in simulated low visibility conditions have been produced. A 16 mm version entitled "Fog Visibility Study, Series III" has been made available to airlines as a training aid. To date 30 copies have been sold and 4 copies have been given to governmental agencies and aircraft manufacturers.

In May 1971 a 35 mm film consisting of 12 composited scenes showing a pilot's view of the landing sequence as though he were flying a 707 aircraft was delivered to FAA. This film includes several approaches with the approach system lights and the runway lights depicting various percentages of outage. The purpose of the film is to permit FAA to display this film to a large number of airline pilots, FAA personnel and airport operators and determine from their reaction the upper limit of random outage that can be permitted on an approach and runway lighting system. The film can also be used as an orientation aid for pilots to familiarize them with what to expect to see when landing under reduced visibility conditions.

Over the period of years since the completion of the Fog Chamber, many governmental agencies and companies have made use of the unique features of the Fog Chamber for studies in low visibility. A partial list of these is as follows:

1. Joint Venture, Belgian Airport and Airways Agency and Ateliers de Construction Electriques de Charleroi. Reported in FAA RD-67-32, "Final Report Tests on ACEC Videometer in Fog Chamber at UC Berkeley, USA." Under project No. 430-302-01N. Feb. 1967.
2. Sylvania Electric Products, Inc. Evaluation of Gated Luminaires in Fog. July 1968.
3. Texas Instrument Co. Evaluation of Forward Looking Infrared System for U S Air Force. January 1967.
4. Automobile Manufacturers Association. Determination of the Efficacy of Red, Green, and Amber as suitable colors for Automotive Rear Lighting in Low Visibility Conditions. April 1966.
5. Einac Division of Varian. Human Eye Response to Low Intensity Navigation Lights for Space Craft Rendevous and Docking Maneuvers. April 1967.

6. Bendix Corporation, Navigation & Control Division. Fog Simulator Program. Under FAA contract FA 67WA-1770. Nov. 1967.
7. Panama Canal Zone. Development of Variable Intensity Navigational Lights for Sections of the Panama Canal. 1968-69.
8. California Division of Highways. Fog Accident Prevention Study. 1965.
9. Santa Barbara Research Center. Study of Active and Passive Infra Red Detection Systems. Dec. 1969.
10. Mercedes-Benz of North America. Static and Dynamic Evaluation of Mercedes-Benz Turn Signal to Headlamp Spacing Relationship. Static tests run in Fog Chamber under low visibility conditions. Nov. 1969.
11. Golden Gate Bridge Authority. Evaluation of Center Line Lights for Automotive Guidance in Low Visibility Conditions. 1965.
12. Division of Bay Toll Crossings. Evaluation of Continuous Bridge Lighting Under Low Visibility Conditions. July 1971.
13. Air Force, Department of Defense. Study of 1. Air Force Security Devices. April 1969.
14. American Airlines. Sonic Fog Dispersal Study. 1969.
15. General Precision-Singer Corporation. High Intensity Infra Red Source as a Fog Dissipator and Fog Penetration by 3×10^6 cp Light Source. May 1970.
16. California Highway Patrol. Evaluation of Reflex Reflectors Under Low Visibility Conditions. Feb. 1968.
17. Department of Transportation, National Highway Safety Bureau. Contract No. FH-11-6549, Glare and Driver Vision. Aug-Sept. 1968.

Any funds derived from these activities for the use of the Fog Chamber have been credited to the ARDS-434 account. Staff support was charged directly to these programs and reduced the staff costs for the FAA contract. FAA has benefitted from most of these programs indirectly or directly by

- 1) additional knowledge acquired by the staff on low visibility problems, and
- 2) reports from contracting agencies supplied to FAA.

In the nine year period encompassing the ARDS-434 contract, over 1200 individuals have signed the guest roster. The preponderance of these people have been directly associated with some phase of aviation activity. Representatives of aviation activity or interest from 21 foreign countries are included in the group. Several newscasts utilizing the Fog Chamber activity have been broadcast locally and on nationally syndicated programs.

**University of California-Federal Aviation Administration Fog Chamber
Test Facility**

This section of the report contains general structural information and other details of the test building (also known as the "Fog Chamber") as well as a description of the various functional features that make up the test facility. Included in the latter category is a detailed description of and operating data on the tramway system used for simulating landing approaches and the fog generation equipment.

Test Building

Structural Information. The test building is a wood-frame structure. The basic dimensions are 1000 ft long x 30 ft wide x 30 ft high at the approach end. The dimensions were selected to permit a 10:1 scale factor to be used for simulation studies of the approach and landings of transport aircraft on commercial airports. (See Fig. 1) The drawing shows a longitudinal section (AA) through the centerline of the building, as well as a transverse section (BB) near the high, or front, end of the building and another one (CC) taken through the constant-height portion of the building.

Figure 2 presents details of the roof-truss and other structural features. As shown in the drawing, the lower portion of the sides of the building (up to varying heights in the sloping-roof section) is covered with corrugated sheet steel panels. The upper portion of the sides, as well as the roof, is covered with translucent corrugated fiberglass panels to allow for the entry of daylight into the building.

The electrical distribution system, consisting of the low-voltage feeder wires in conduits and junction boxes, is buried in the asphalt-concrete floor of the building. Longitudinal and transverse channels under the surface of the floor provide wiring raceways for installation of the circuits for the approach and runway lights. This system originally gave great flexibility in the placing of the test lights, allowing for many different patterns and various longitudinal spacings. However, at the present time the floor of the building has been paved as a solid slab over the entire conduit, junction box network and channels with circuit connections brought out only at the surface mounted lights. Standard US and ICAO approach light patterns and runway light patterns are available. The various components of the system can be switched on and off and changed in intensity.

At the front of the building is a three-story section housing the observation and control rooms, as well as maintenance and storage facilities. Fig. 3 is a view of the building interior, from about the midpoint toward the front end, showing the approach and threshold lights set in the floor. Fig. 4 is a view toward the rear showing the constant-height portion of the building with the runway lights set in the floor. Also shown in these photographs is the tramway carriage as seen from the front and rear, respectively.

Functional Features. Electric power, water and compressed air required for operating the test facility are provided as follows:

- | | |
|----------------|--|
| Electric Power | a. 30 kva at 480 v, 3 ϕ , 60 Hz stepped down to 240v, 3 ϕ for rails on tramway. Used with SCR, DC speed control for tramway motor, cockpit control and for auxiliary power on the tramway. |
| | b. 25 kva at 220 volts ac, 60 Hz, four 2-120 volt circuits for building lights. |
| | c. 5 12.5-kva regulators fed by 100 kva, 480 v, 1 ϕ transformer for runway lights. |
| Water | - Obtained from municipal supply at nominal inlet pressure of 80 psi. |
| Compressed Air | - Four diesel-driven rotary compressors provided a total of 2400 cfm at 125 psi. |

Service facilities for equipment and building maintenance include a shop area with work benches and hand tools, a storage area for spare parts and equipment, instruments and other material. Among the major items of maintenance equipment are a tractor, used for moving equipment down the length of the building, and a movable scaffold for access to the tramway carriage when stopped in the sloping-roof section of the building.

Tramway System

Structural Features. As shown in Figure 5, the tramway system consists basically of a cockpit housing suspended by a trolley from a carriage framework that travels on two overhead rails along the entire length of the test building. The basic dimensions of the tramway and its major structural parts are given in the drawings of Figures 6, 7 and 8.

As shown in the drawings, the tramway carriage has a structural steel framework with two suspension type wheel-trucks at each end. Each truck has four polyurathane covered steel wheels that roll along the lower flange of the overhead I-beam rail.

The cockpit is an actual part of a Cessna aircraft hung from a trolley on the tramway. The trolley from which the cockpit is suspended can be moved by a power driven mechanism to give a lateral displacement of up to 10.5 feet on each side of center (equivalent to an off-center approach of 105 feet in actual practice).

A noteworthy feature of the tramway system is the relatively good dynamic stability obtained even with the cockpit housing displaced laterally to its farthest position from center and the carriage traveling at maximum speed.

Functional Features. The tramway carriage is driven by a 15 hp, DC, electric motor which can be operated over a wide range of speeds with DC control obtained through SCR units from 240 volts AC on the rails. The motor is coupled to the drive shaft through a 3-speed transmission assembly. The shaft, in turn, rotates a pair of polyurathane covered drive wheels that are spring loaded against the underside of the tramway rails.

Figure 9 is a schematic diagram of the drive control circuit. A hand lever inside the cockpit (Fig. 10) controls the speed of the drive motor so as to provide the carriage with five forward and five reverse speeds ranging up to a maximum of 15 mph (nominally) in the forward direction. Braking of the carriage is accomplished by an electrodynamic and a magnetic brake. Both operate automatically when power is shut off from the drive motor. As soon as power is removed from the motor, a low-resistance load is connected across the armature so that the motor acts as a generator and, due to the large load current, offers very high resistance to rotation. This system provides very effective dynamic braking. In addition, with drive power removed, the magnetic brake (see Figure 5) is de-energized, allowing a pair of spring-loaded brake shoes to clamp the drive shaft. The magnetic brake is, in effect, a fail-safe device, since it operates under any condition of power loss.

When the carriage reaches a predetermined point near either end of its maximum travel, a safety limit switch on the carriage is automatically tripped to remove drive power and to apply the brakes. Beyond the point at which the safety limit switch is tripped, the carriage can be driven at slow speed in either the forward or reverse direction by means of a pair of pushbutton controls in the cockpit. These buttons allow the carriage to be moved all the way to either end of the line. A set of shock-absorbing buffers at each end of the rail line provides additional safety if the carriage has not stopped before reaching the end.

For test runs, the cockpit (Figures 5 and 10) has room for two observers sitting in the pilot and co-pilot positions and for an operator sitting behind the observers. A writing shelf at the front of the cockpit provides for data taking, as well as for setting up camera equipment, measuring instruments, or other apparatus. Cockpit illumination is provided by a set of gooseneck lamps mounted two on each side directly behind the windshield.

The outside of the windshield is kept free of moisture by a forced warm-air system consisting of two blowers and an electric heater. Ordinary wipers could not be used because the windshield is made of plastic.

Power for auxiliary systems, such as the cabin air conditioner, is taken from the rails, using 3 single phase circuits (one from each of the 3 phases), each of which delivers 120v AC from a 1 kva, 240-120 volt transformer.

While the carriage is stationary, 120-volt AC power (for special instrumentation) can also be brought into the cockpit through a cable that plugs in at the front of the cockpit housing. The 120v AC voltage can be picked up at any of the several outlets along the sides of the building and can be varied continuously from zero to maximum by a voltage control inside the cockpit. To keep the carriage from being inadvertently set in motion while the AC cable is connected, a warning buzzer sounds if the carriage is started while the cable remains plugged in at the cockpit.

With the carriage parked, moreover, the fog-generating system in the building can be controlled from the cockpit through another cable that also plugs in at the front of the cockpit housing. In addition to fog control, this cable also provides for telephone communication

between the cockpit and the control room. When the carriage is in motion, communication between cockpit and control room is carried on by means of an intercom system operating through the power buses.

To accommodate for the filming reported in "Development of Filming Technique for Runway Lighting (Aug. 1971)," certain modifications were made to the cockpit. The front of the lower portion of the cockpit was modified to provide a large window. Provision was made to bolt a special camera mount to the floor with the camera sighting through the window. To provide the necessary realism to the films, the external scene must appear to pitch, roll, and yaw. The cockpit on the tramway is capable of longitudinal and lateral motion as well as yaw. However, the yaw motion of the cockpit could not be used because from the pilot's view point or eye position the external scene moves relative to his eyes. Since the camera had to be mounted forward of the axis of rotation for yaw, a distorted view would be seen in the film; therefore, the yaw motion of the cockpit was not used and all pitch, roll and yaw were accomplished in the camera mount with rotation taking place about the nodal point of the camera lens system.

Figure 12 shows the camera mount in the cockpit. The mount was bolted to the floor of the cockpit and adjusted to a height to represent the accepted pilot's eye height for the 707 aircraft. Mounted in front of the camera and forming the window through which the filming was done was a double glass square. Each square could be rotated independently by synchronous stepping motors. The glass in the windows was selectively given a ground glass finish in such a manner that in daylight the normal background brightness gave the appearance of fog. By adjusting the rotation of these glass elements, the field of view of the camera was restricted to an area closely approximating the perspective view of the runway at any given distance or altitude. This successfully masked out the actual building structure from the film, but permitted the normal wide angle view of the lens. Hot air blower kept the windows from being fogged by impact during a travelling filming sequence. Figure 13 shows the perspective screen in place. The selectively ground glass windows have been removed for purposes of taking the photograph.

Fog Generating System

Basically, the fog is produced by allowing a combination of compressed air and water to be sprayed out through a number of atomizing nozzles. The nozzles are distributed along the sides of the test building and are supplied with air and water through a system of pipes as shown in Figure 11. Four diesel-driven rotary compressors are available to provide the compressed air. Normally two 600-cfm, 125 psi compressors are used during a test. The water comes from the normal municipal supply.

As indicated in Figure 14, the fog generating system consists of a number of nozzle manifold assemblies connected to the air and water supply pipes at various points along both sides of the test building. Each manifold assembly is one of the four types shown, depending on where in the building it is located. In general, the nozzles are spaced in a way that helps to provide a uniform fog density, taking into account the fact that various sections of the building have different volumes. The Fog Chamber is now equipped with a total of 130 fog nozzles.

Figure 14 shows a typical manifold assembly, while Figure 15 is a closeup showing the spray as it leaves the nozzle. The spray is turned on and off by controlling the flow of water to each nozzle with a solenoid valve (as described later). To control the size of the fog particles, the air-to-water pressure ratio can be adjusted by means of the pressure regulators for each nozzle. The usual setting is for intermediate sized particles (10-20μ) which requires 60 psi air pressure and 40 psi water pressure.

Starting with no fog in the test building and operating continuously, the system is capable of producing a fog density equivalent to a 1200 foot visual range in 2 to 3 minutes.

Control System - Fog Generation

Besides turning the entire fog generating system on and off, the main function of the control system is to maintain as nearly uniform a fog density throughout the test building as possible for test periods lasting up to several hours. Since the rate at which the fog decays is highly dependent on such factors as temperature, dewpoint, movement of air, etc., the biggest problem in maintaining uniformity lies in compensating for the differences in environmental conditions at various points in the building.

To help overcome this problem, the fog generating system, as indicated schematically in Figure 16, is divided into 22 sections for control purposes, each section consisting of a number of nozzles with their corresponding solenoid valves. The solenoid valves are operated through switching control circuits in such a way that the nozzle sections can be individually controlled either by manually operated console switches or by an automatic cycling device.

Figure 17 shows the control circuit for one group of nozzles in schematic form, the circuits for the other sections being identical to the one shown. The cycling is achieved by a servo-control system coupled to the 22 separate short base line IR transmissometers located throughout the Fog Chamber. A back-up control system (the initial controller) consists of cam-actuated microswitches with an adjustable-speed motor driving the cams. The period of the operating cycle can be varied by changing the speed of the cam motor, while the duty cycles for the control circuits can be adjusted either individually or together by varying the cam-to-switch spacing. This mechanical system is used when very dense fogs are required in which the IR transmission is too low for reliable and consistent control action.

The 24-volt control relays are of the split-coil type in which the contacts remain open or closed, depending on which half of the coil has been energized. Inasmuch as these relays require only momentary application of energizing voltage to operate, each control circuit includes an RC network to provide an electrical pulse for the on and off sections of the relay coil when the cam switch is closed and opened respectively.

Table 1 gives a detailed description of the major components in the control system.

TABLE 1. FOG GENERATING SYSTEM COMPONENTS

Item	Description	Manufacturer and Model
Air Compressor	Diesel-driven rotary 600-cfm capacity at 125 psi.	LeRoi, Model 1200 RD2
Spray Nozzle	Pneumatic atomizing nozzle providing wide-angle, round spray pattern.	Spray Systems Co. Type 1/4 J with Spray Setup No. 29.
Pressure Regulator	Adjustable, 0-200 psi range.	Wilkerson Type 2000-2G
Solenoid Valve	115-volt, with 1/4 inch inlets.	Milmac Type J-2
Control Relay	24-volt, split-coil type	GE Type RR-3
Relay Transformer	120:24 volts, with built-in thermal breaker.	GE Type RT-5
Indicator-Lamp Transformer	120:6 volts, doorbell type	Edwards Type 996
Console Switch	Normally open, single pole, double throw, momentary contact type.	GE Type RFS-6

Test-Light Circuits and Controls

This section provides general information on the electrical system for the test lights as well as a brief description of the means by which the lights are controlled.

Electric power for the test lights is obtained from the two 120-volt ac lines supplying the test building. The lights are connected in 35 switched circuits and are energized through low-voltage transformers in each circuit. Figure 18 shows the general layout of the electrical system for the test lights; Figure 19 shows a typical test-light control circuit in schematic form.

As indicated in the schematic diagram, each circuit is provided with a 24-volt split-coil relay which can be controlled by one or more console switches or by a switch on the voltage control board, all connected in parallel. The power for operating all of the circuit control relays comes from a 24-volt transformer hooked up to the 120-volt line, the output of the transformer being controlled by means of another relay of the same type.

To simplify the operation of the test lights, the console switches are arranged to allow various approach and runway lighting patterns to be set up quickly and easily. This is accomplished by grouping the appropriate circuit switches according to corresponding configurations and

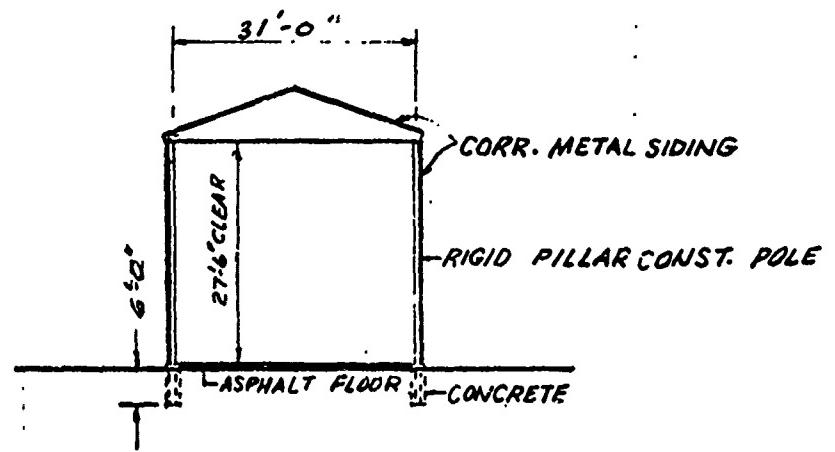
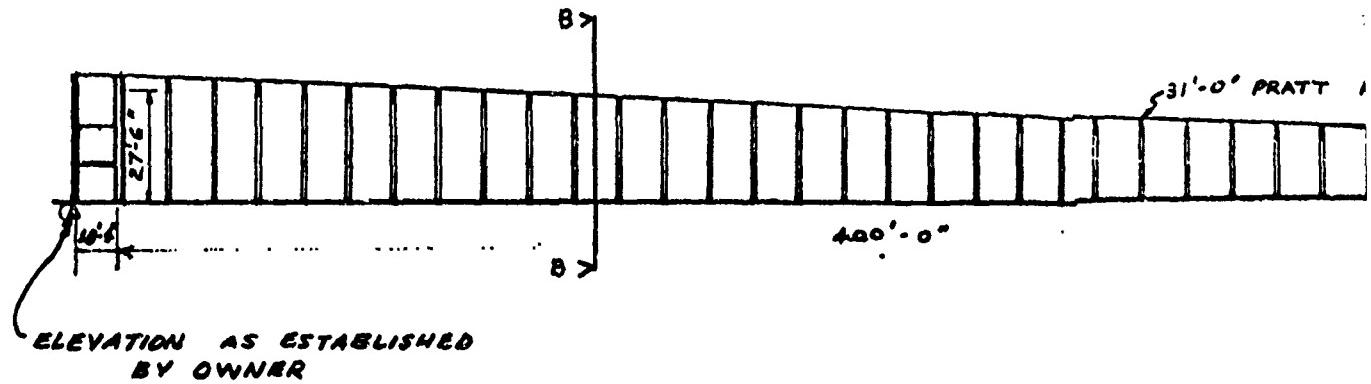
mechanically linking, or ganging, them so that several can be actuated at the same time. The intensity of the lights is adjusted by means of variac-type voltage controllers located behind the circuit-breaker panels (Figure 20); a voltmeter connected across the output of each controller can be set at various fixed intensity levels.

To obtain as nearly uniform an intensity as possible for all lights in a given circuit, the low-voltage feeder lines must be connected so as to maintain the same voltage across each of the lights. This is especially important in view of the fact that the lights draw a considerable amount of current and thus produce sizable voltage drops in the feeder lines themselves. The point is illustrated in Figure 21, which shows the wiring of the threshold lights and portion of the approach lights.

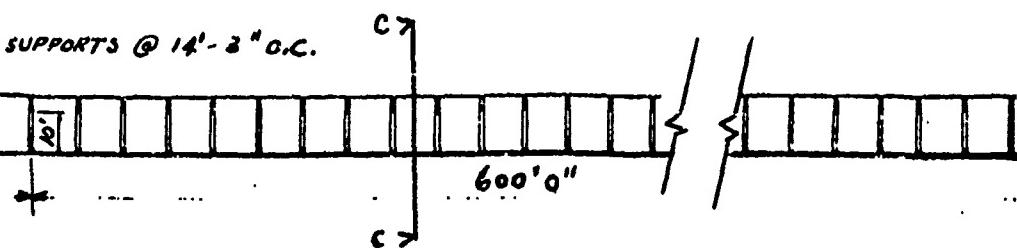
Table 2 describes the major components of the electrical system.

TABLE 2. ELECTRICAL SYSTEM COMPONENTS

Item	Description	Manufacturer and Model
Circuit breaker	120-volt, 20-amp rating.	Federal Pacific Class N1
Voltage controller	100-amp, 4-section type (25a./sec); 11.5-kva total capacity with output voltage adjustable 0-115 volts.	American Transformer Co., "Transtat" No. 29145.
Voltmeter	0-150 volt ac, 4-1/2 in. panel meter	GE Type AO-92
Control relay	24-volt, split-coil type.	GE Type RR-3
Switch	Normally open, single-pole, double-throw, momentary-contact type.	GE Type RFS-6
Relay Transformer	120:24 volts, with built-in thermal breaker.	GE Type RT-5
Indicator-lamp Transformer	120:6 volts, doorbell type	Edwards Type 996
Test light Transformer	120:5 volts, with primary taps for 105, 110, 115, and 125 volts; 115-amp rating.	Kenyon Type S14940



31'-0" PRATT ROOF TRUSS ON POLE SUPPORTS @ 14'-3" O.C.

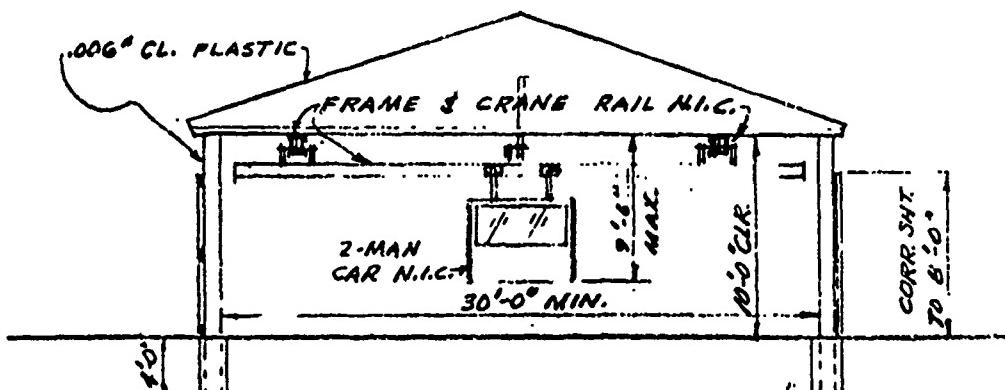


SECTION A-A

NOT TO SCALE'

SIDING

CONST. POLE



SECTION C-C

SCALE : 8" = 1'-0"

B

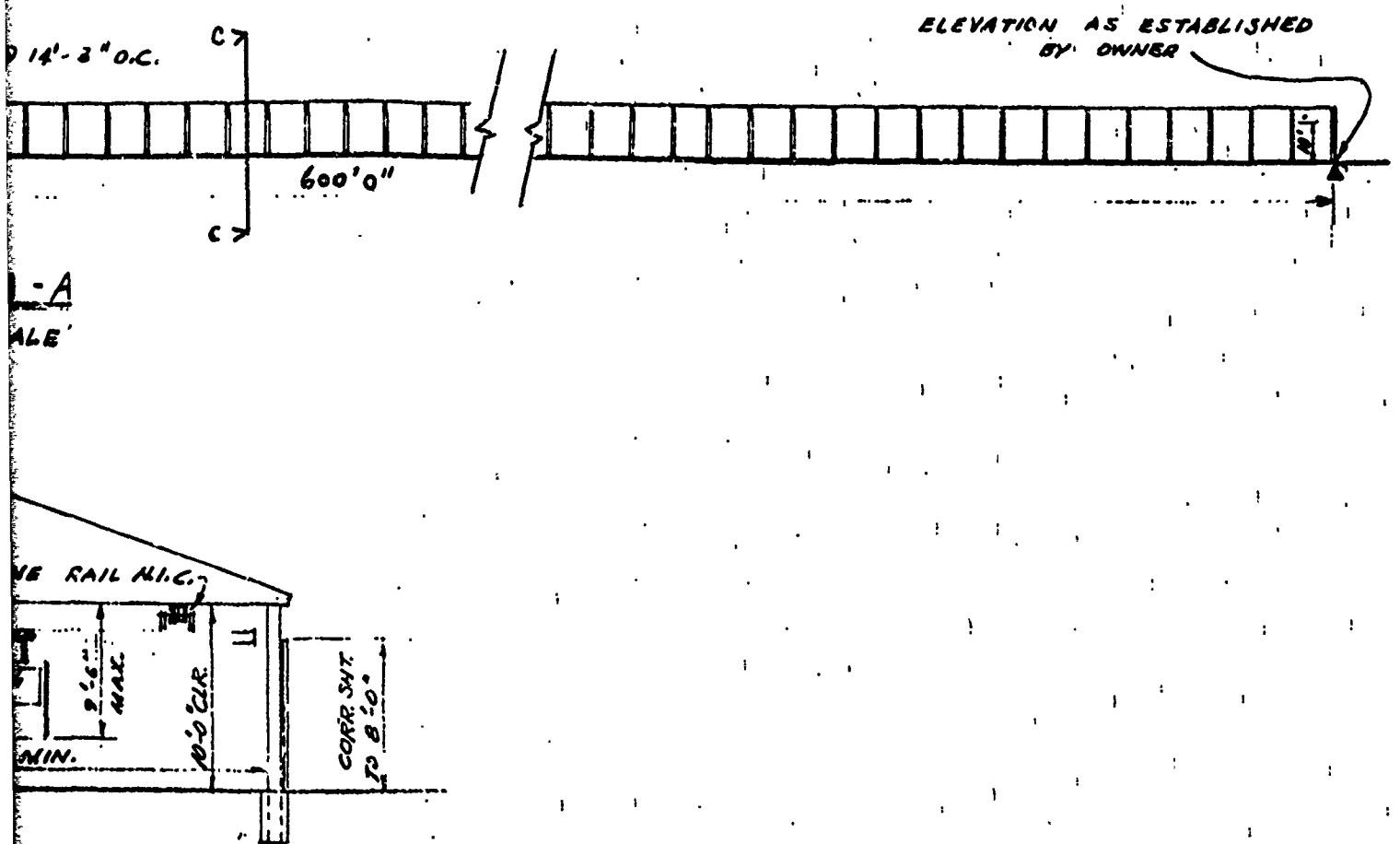


Fig. 1 - Basic dimensions of test building.

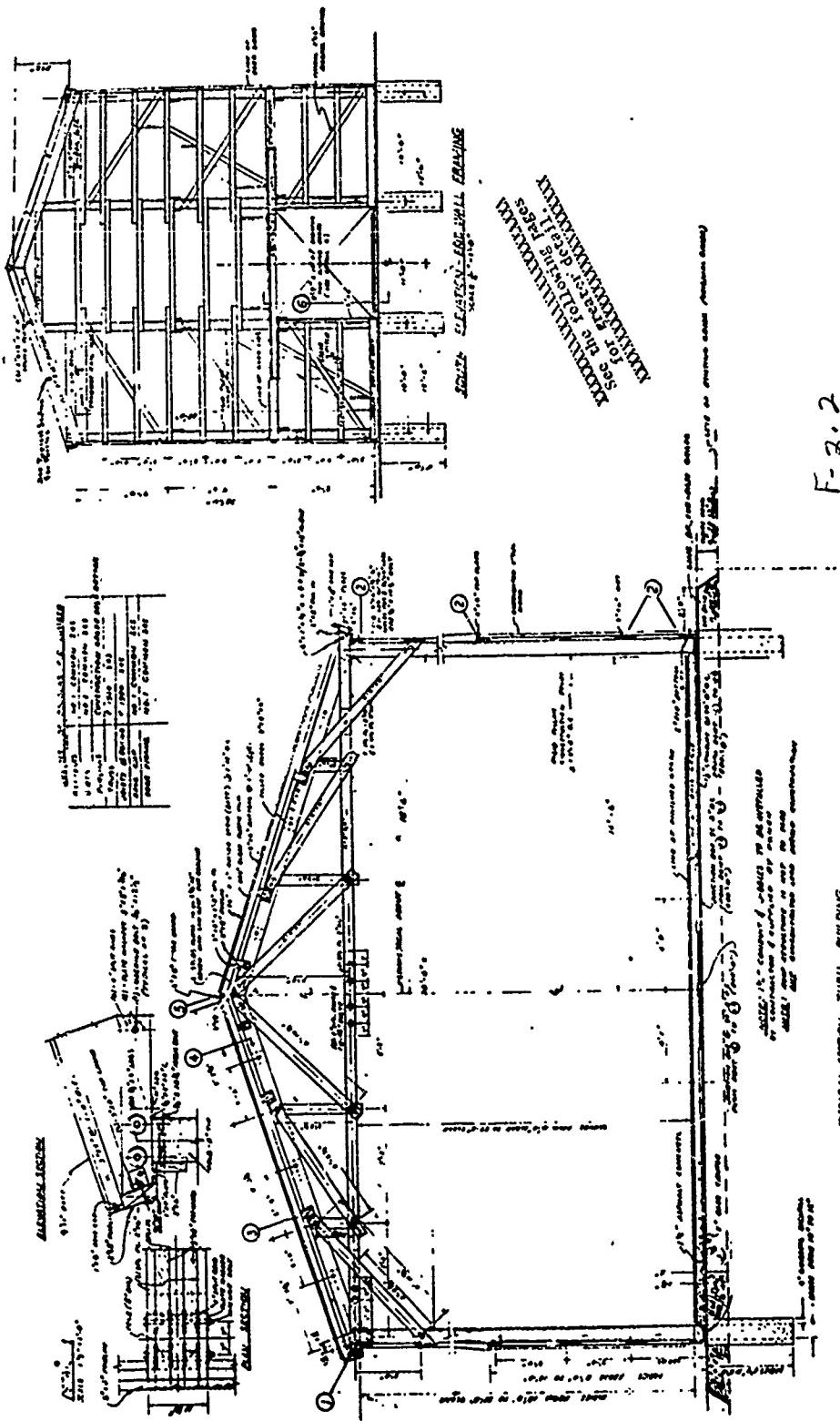
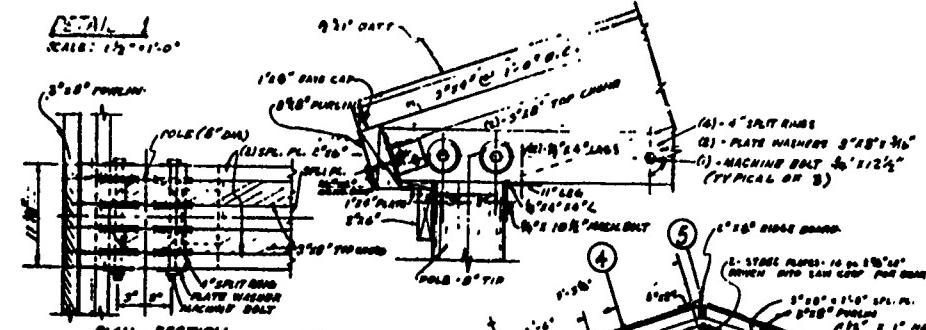


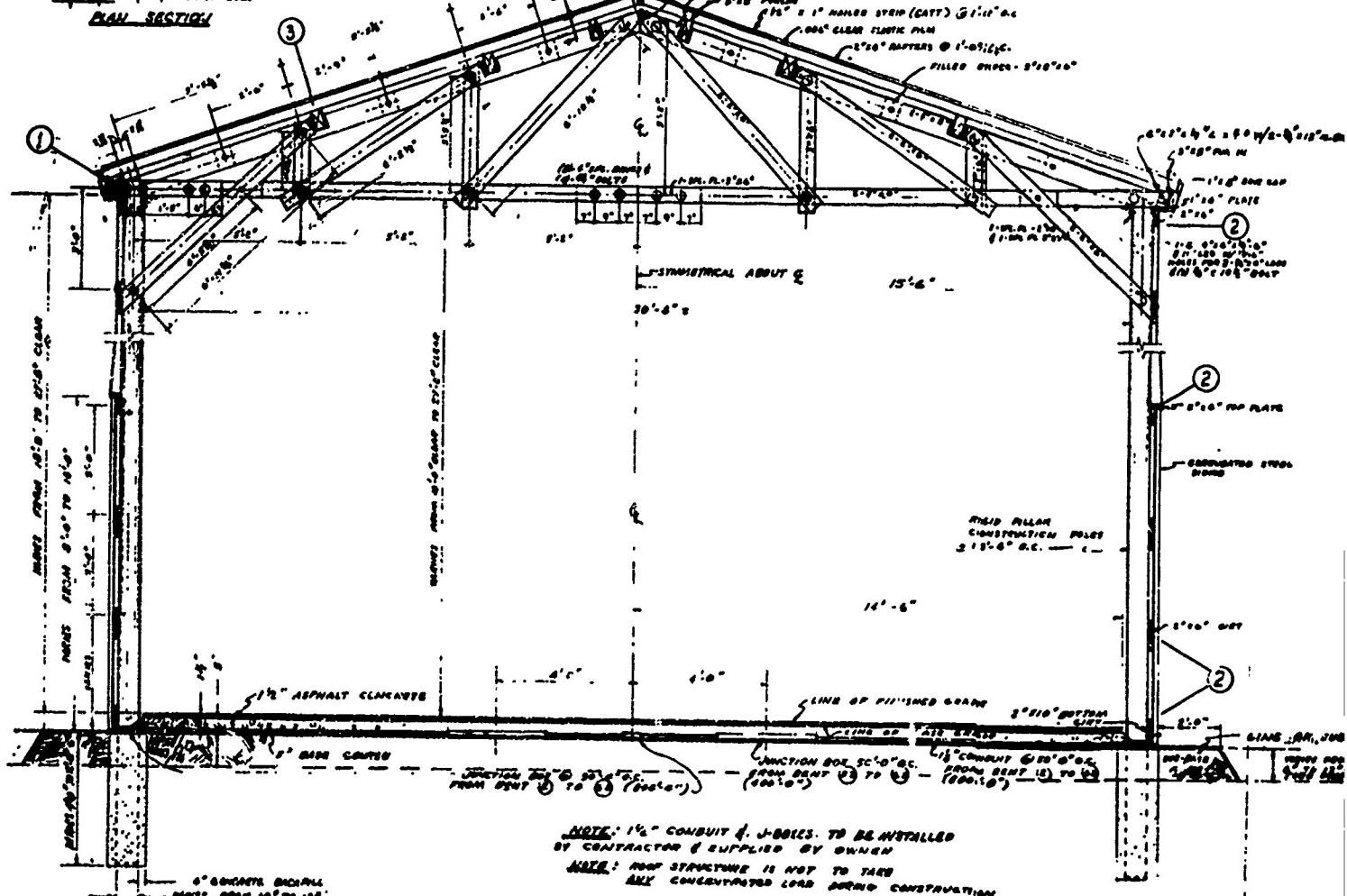
FIG. 2 - Structural details of test building

ELEVATION SECTION



WEALTS OF DOUGLAS FIR LUMBER	
ROOFING	NO. 1 COMMON 8x8
GIRLS	NO. 1 COMMON 8x8
PURLINS	CO. SECTION GRADE 8x8 BOTTOM
TRUSS	7-100 8x8
JOISTS @ 18" O.C.	7-1500 8x8
GABLE CROP	NO. 1 COMMON 8x8
DOOR PIRAME	NO. 1 COMMON 8x8

BAN SECTION



NOTE: 1½" CONDUIT & J-BOLES. TO BE INSTALLED BY CONTRACTOR & SUPPLIED BY OWNER

NOTE: ROOF STRUCTURE IS NOT TO TAKE ANY CONCENTRATED LOAD DURING CONSTRUCTION.

~~STRUCTURE IS NOT TO TAKE ANY CONCENTRATED LOAD DURING CONSTRUCTION.~~

TYPICAL SECTION THRU BUILDING

F-9-1

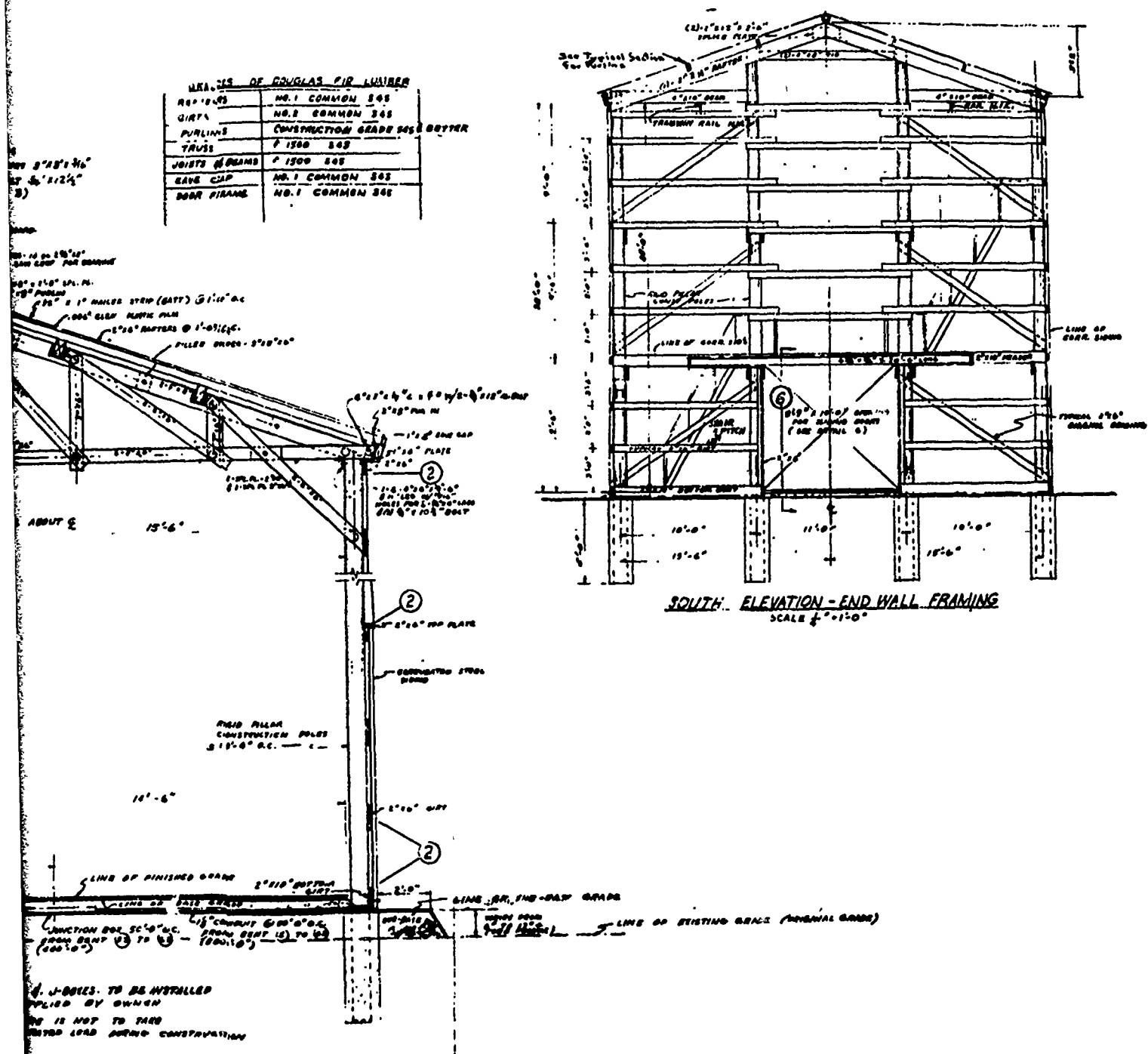


Fig. 2 - Structural details of test building



Fig. 3- Interior of test building looking towards front end.

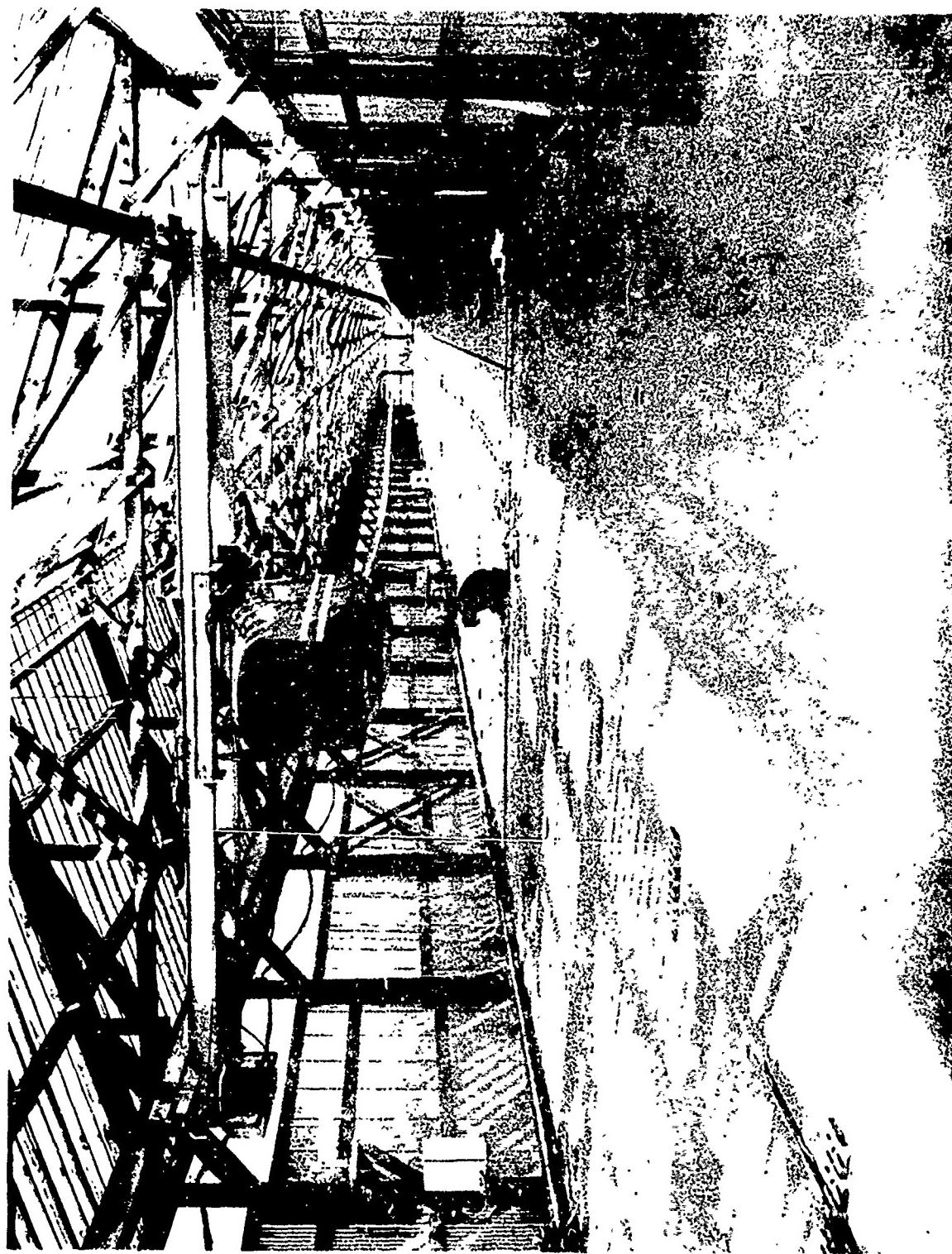


Fig. 4 - Interior of test building looking towards rear.

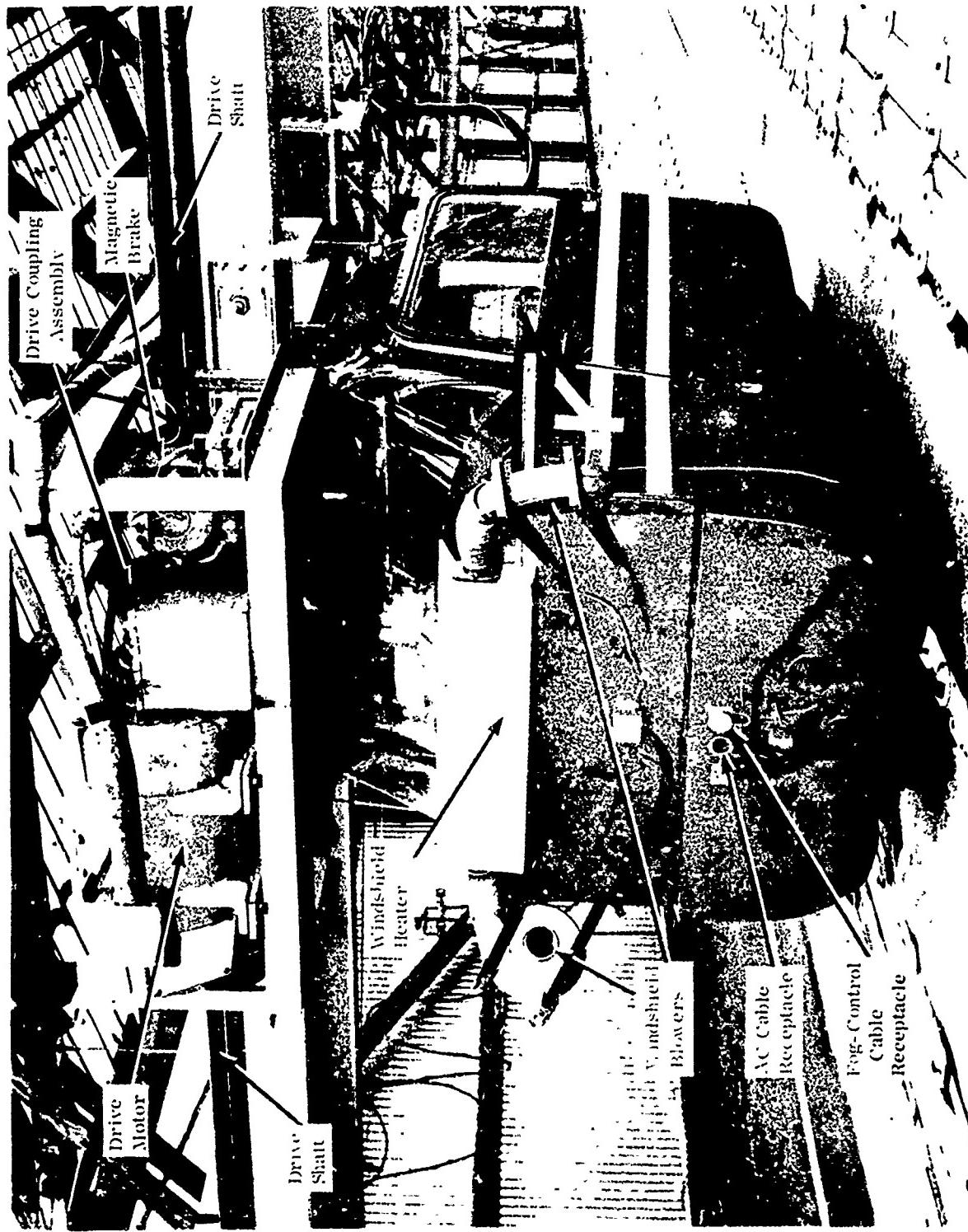
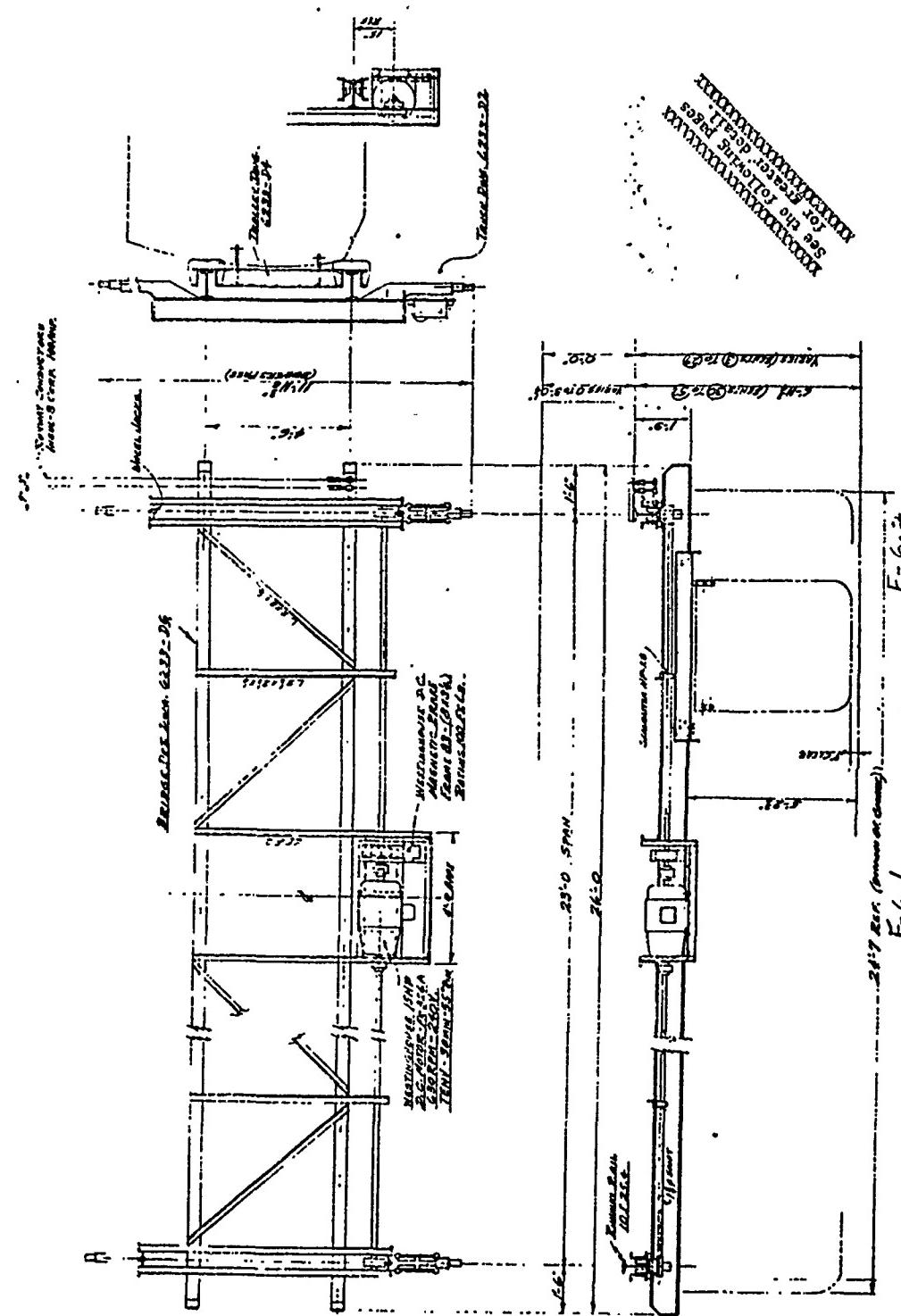
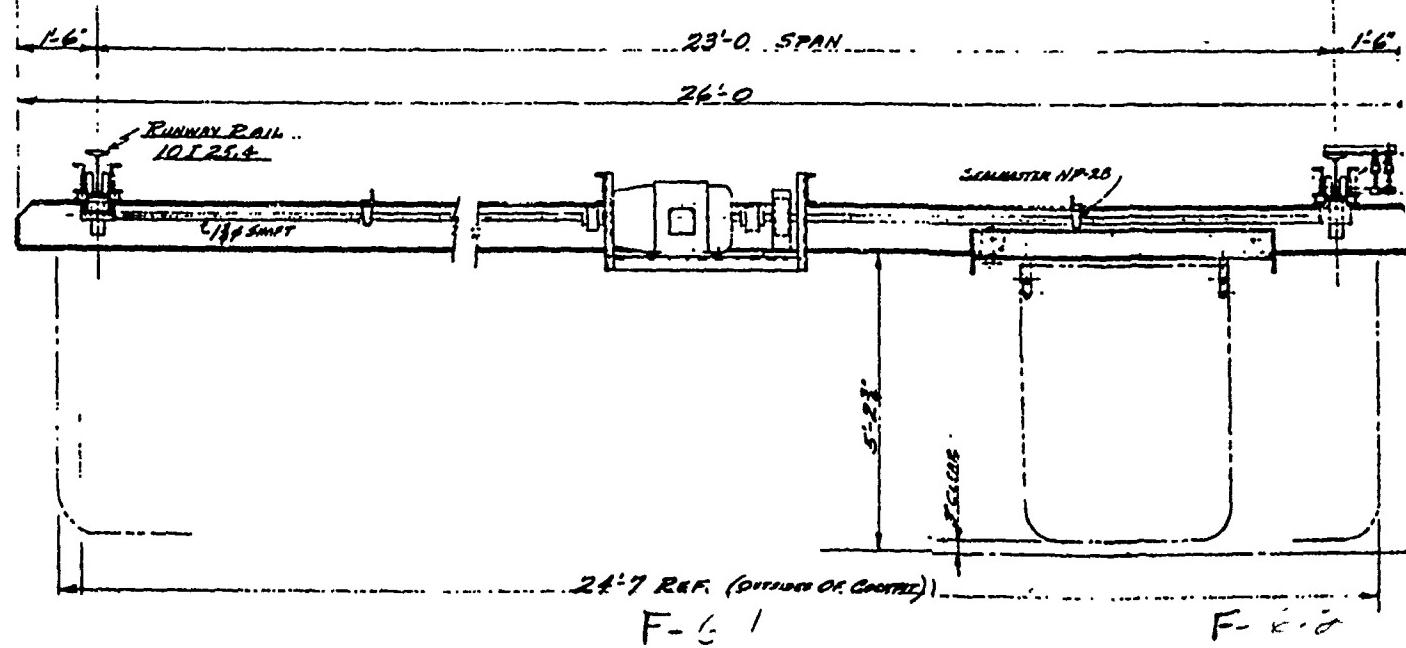
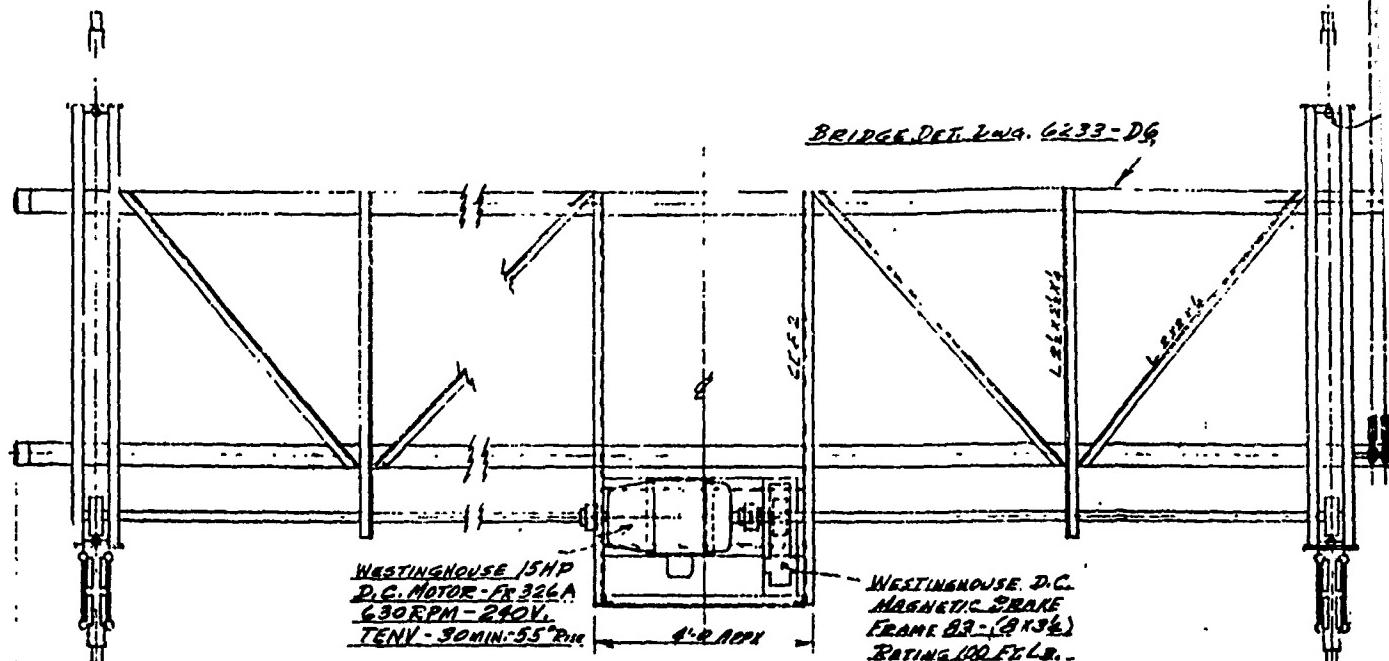


Fig. 5 - Cockpit housing and carriage drive mechanism.



Fri. 6 - Germany outlays [truncated] ~~expenditures~~.

BRIDGE DETAILING 6233-D6



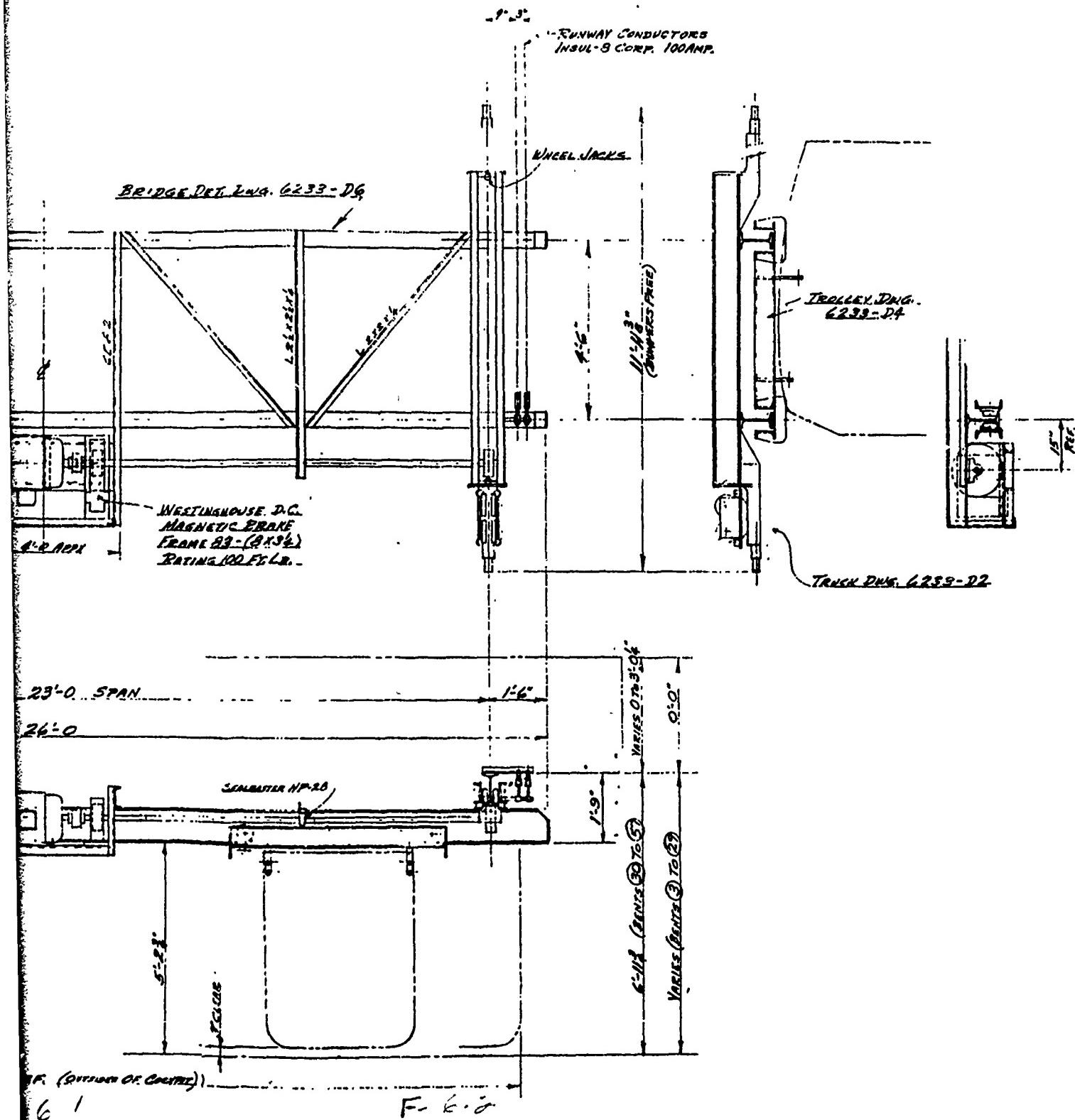


Fig. 6 - Tramway carriage structural features.

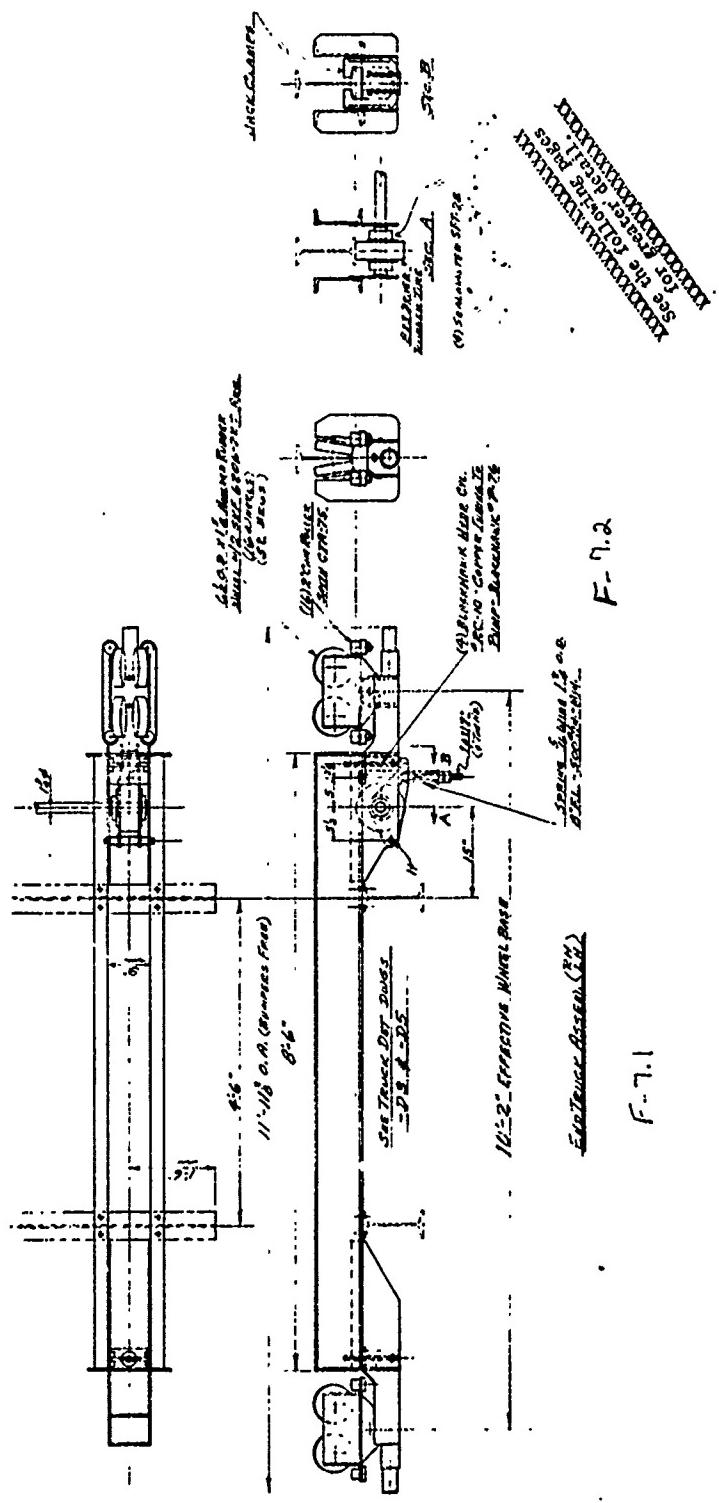
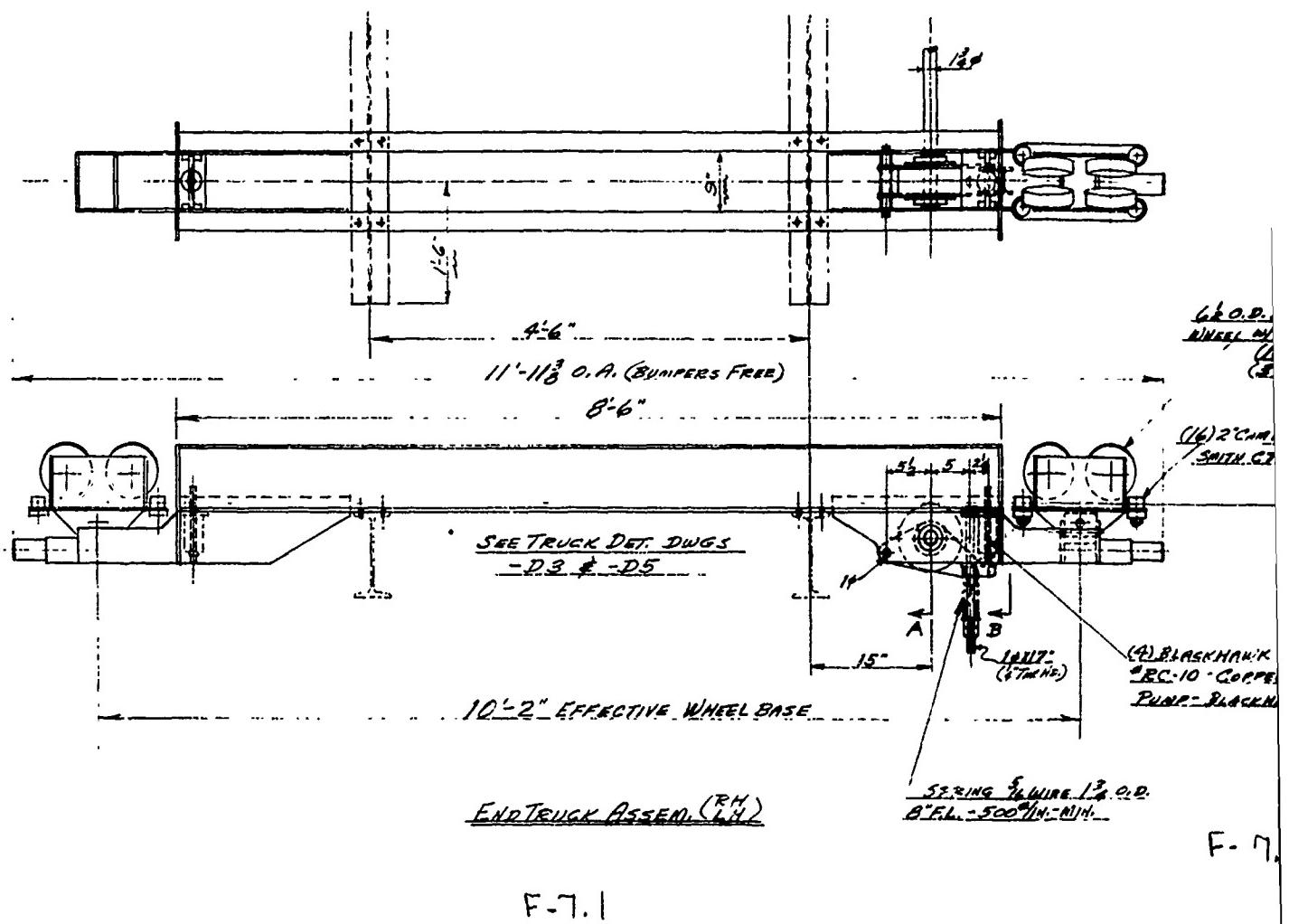


FIG. 7 - Carriage wheel truck details.



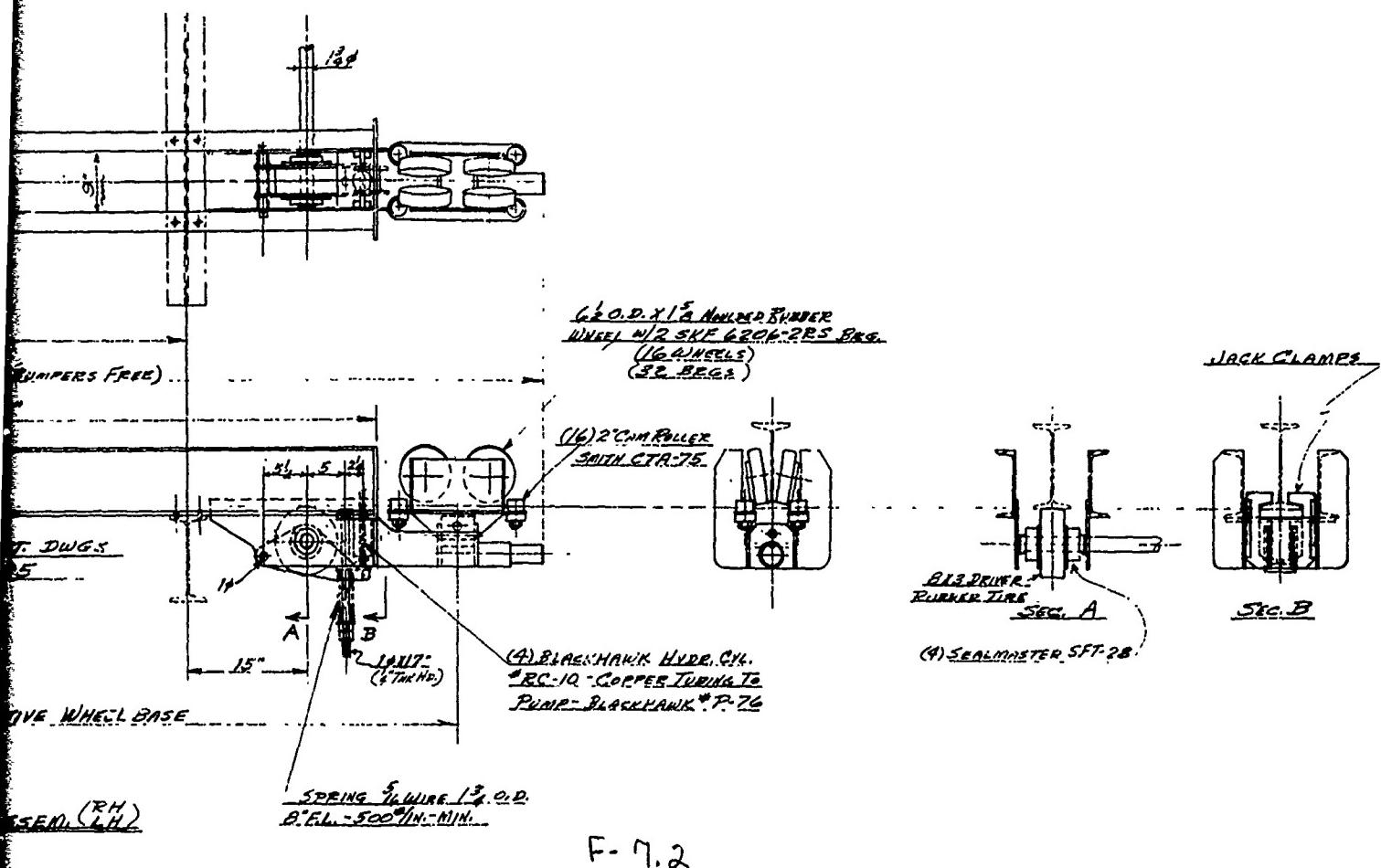


Fig. 7 - Carriage wheel truck details.

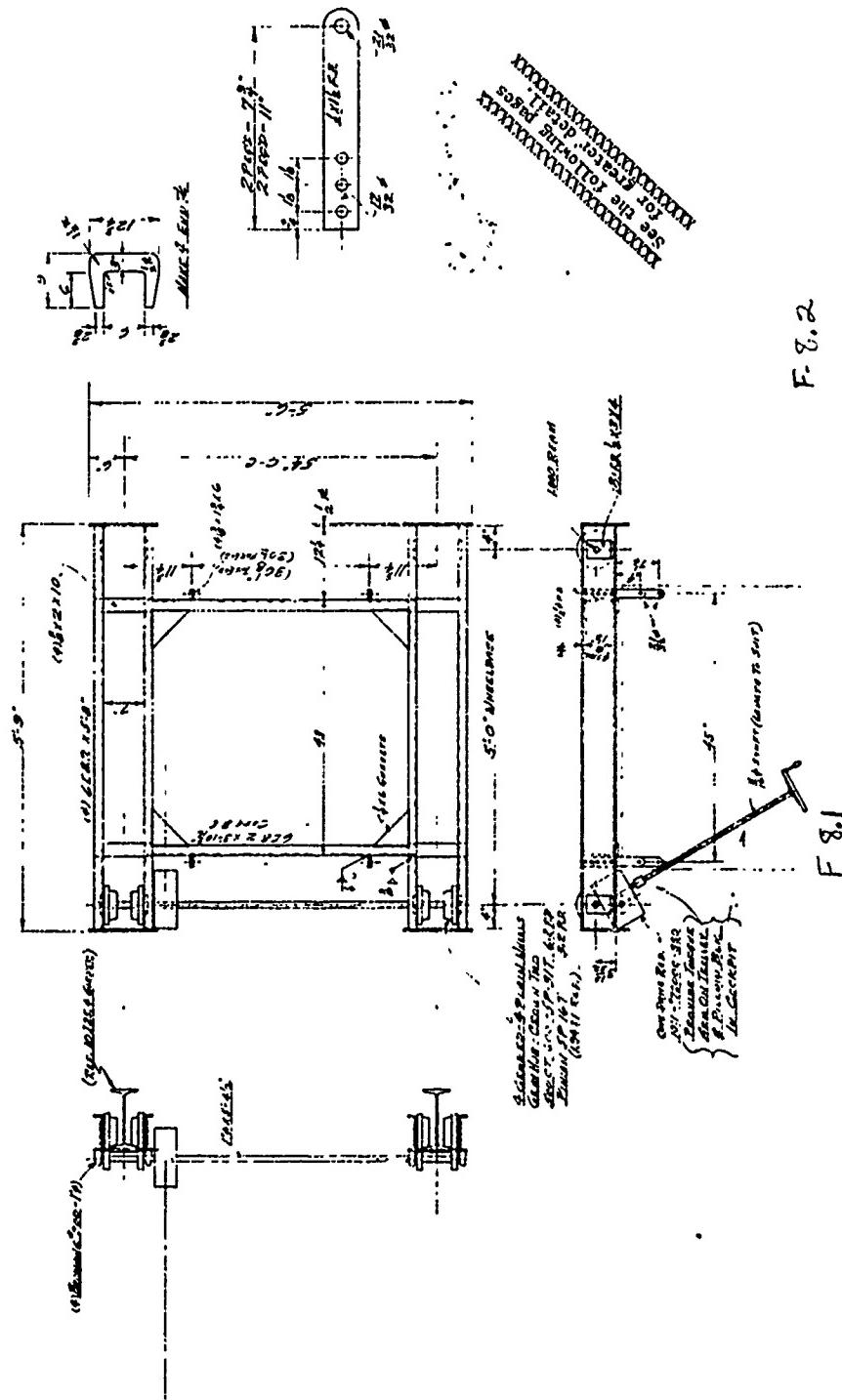
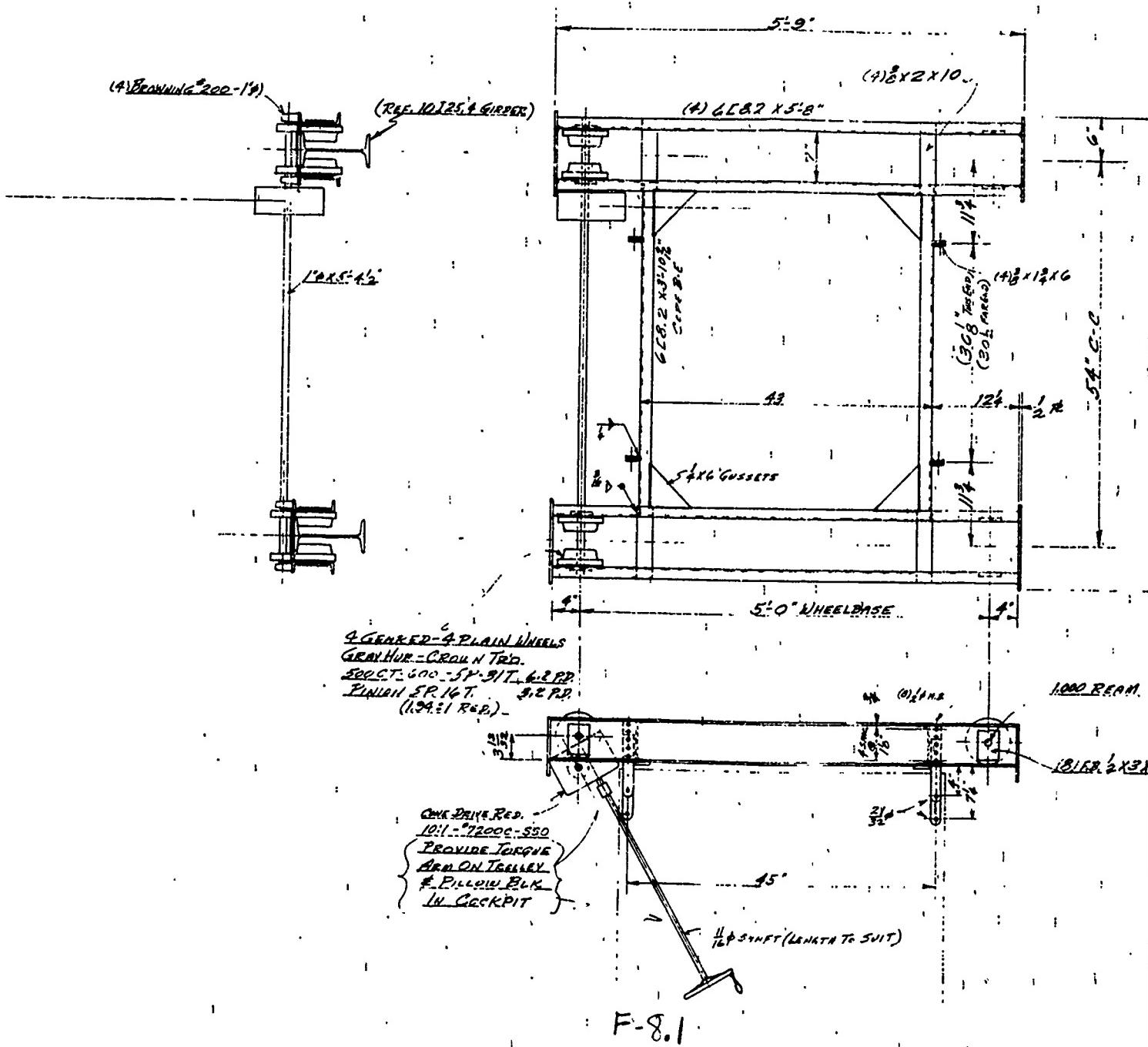
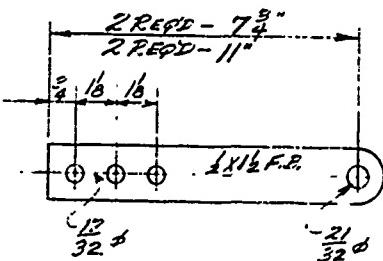
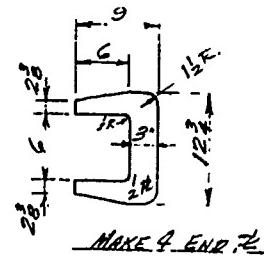
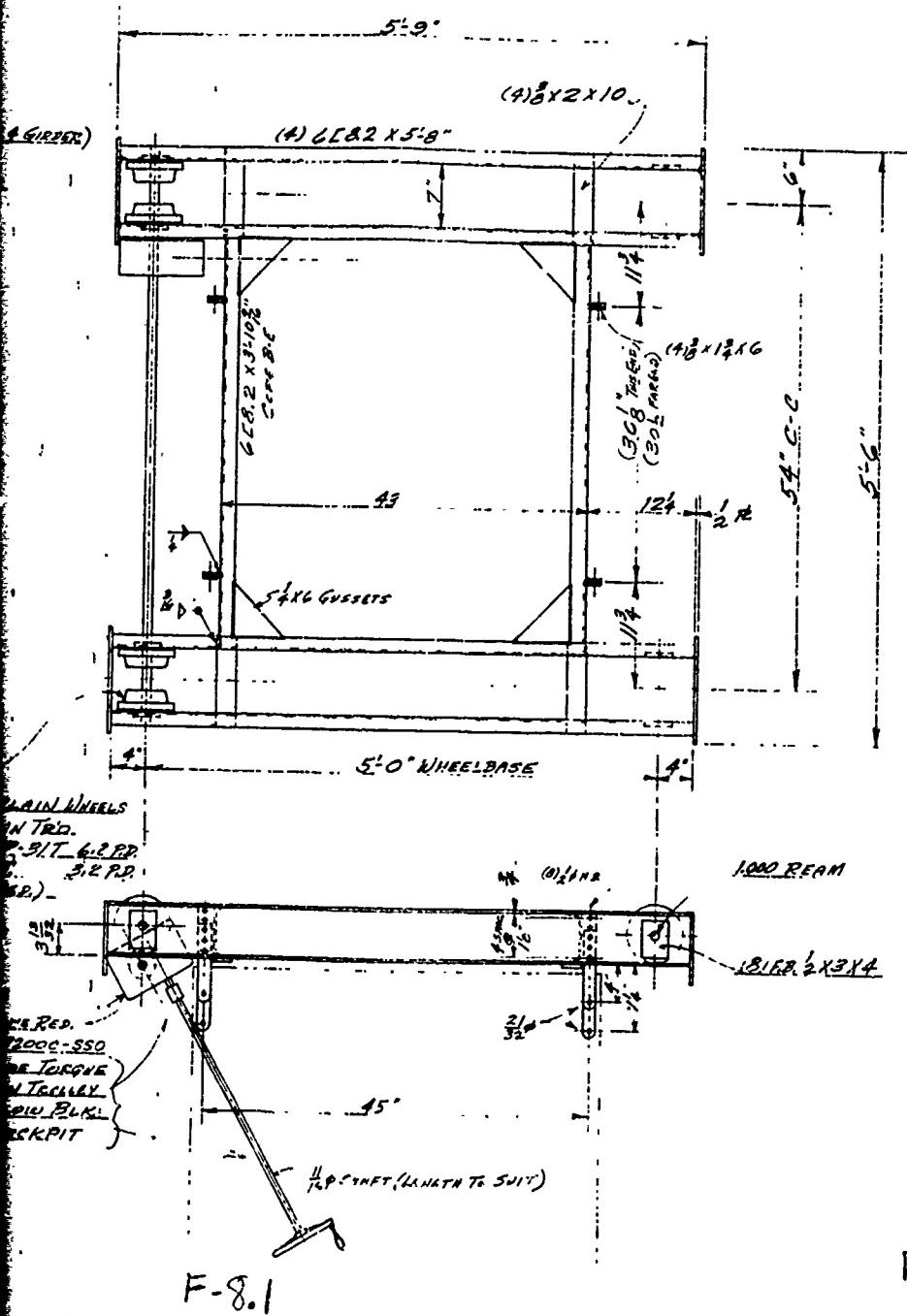


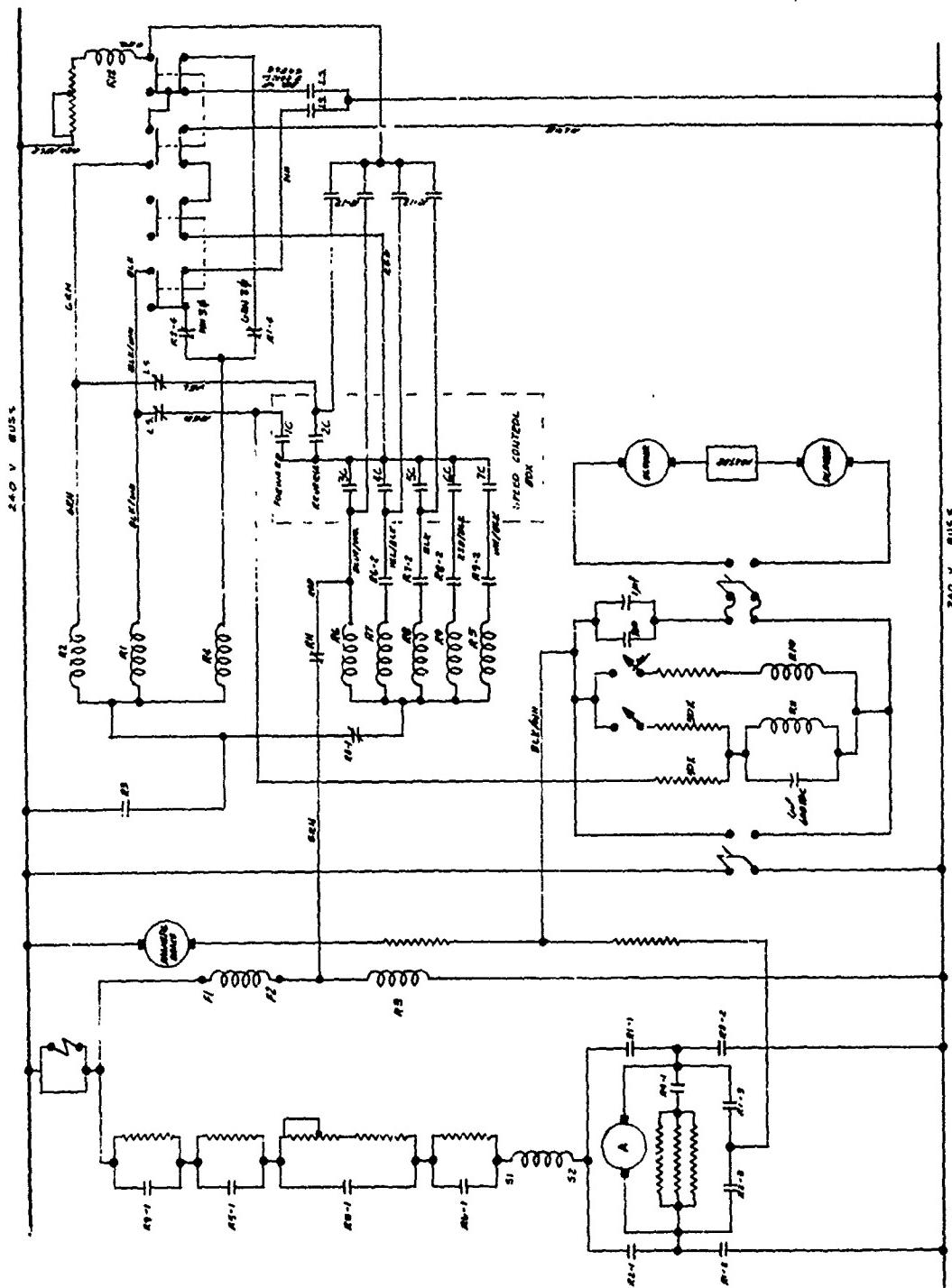
Fig. 8 - Cockpit trolley details.





F-8.2

Fig. 8 - Cockpit trolley details.



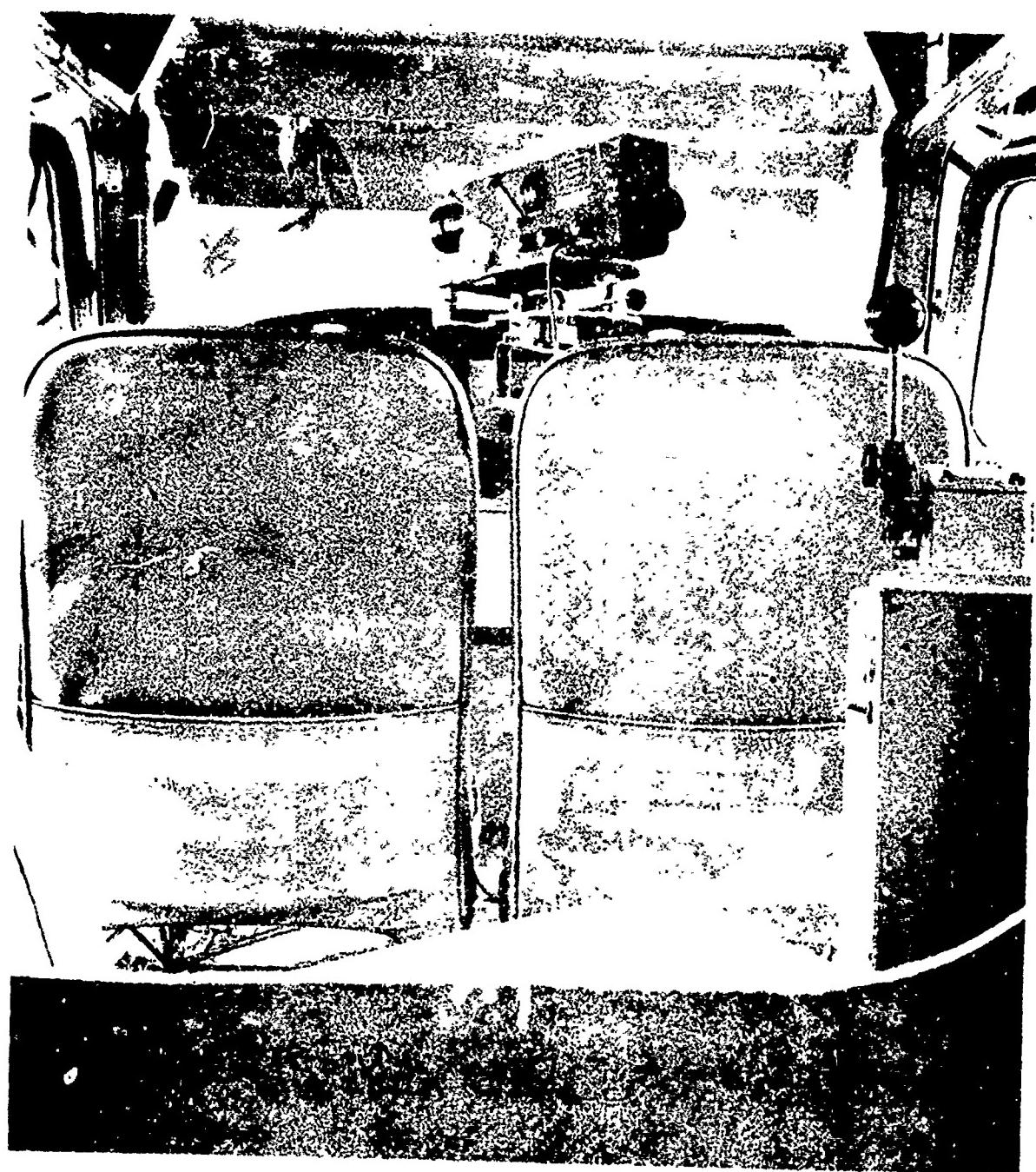
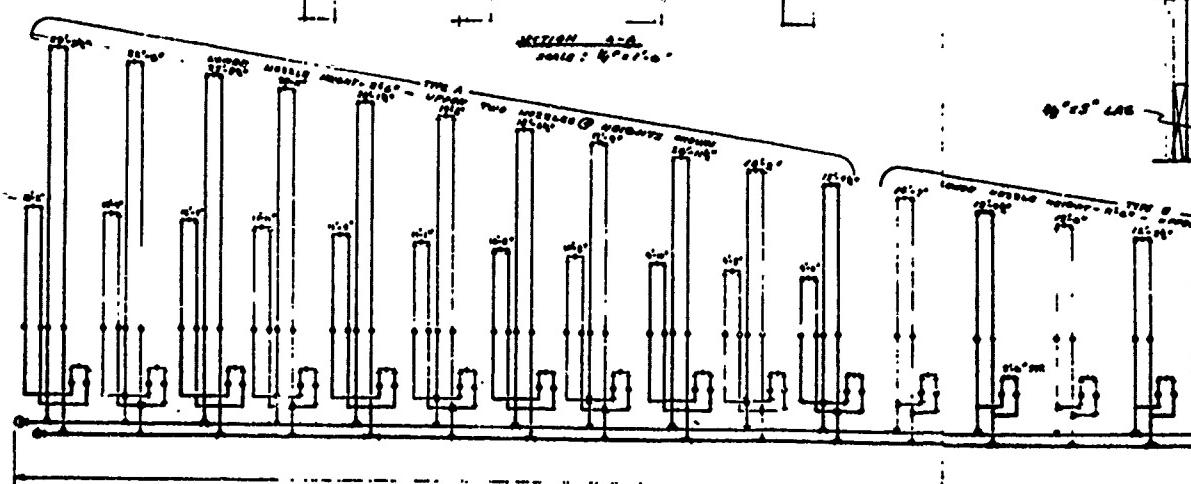
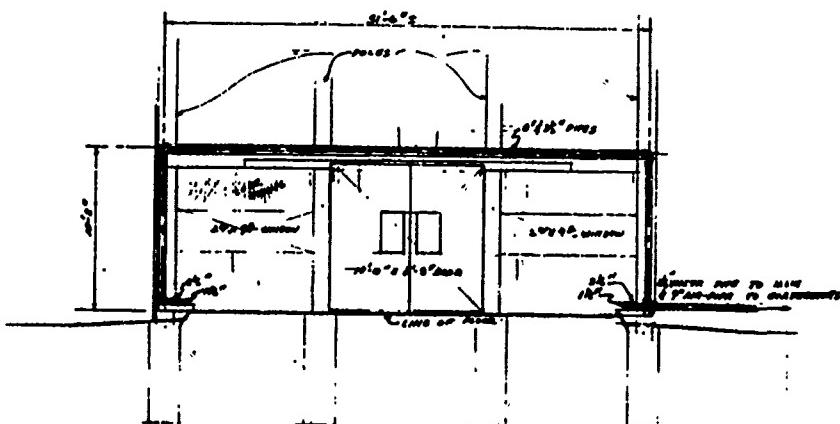
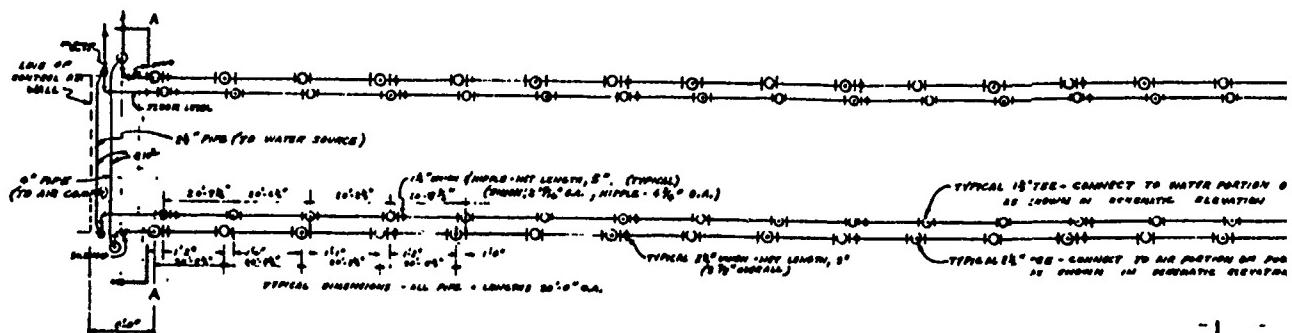
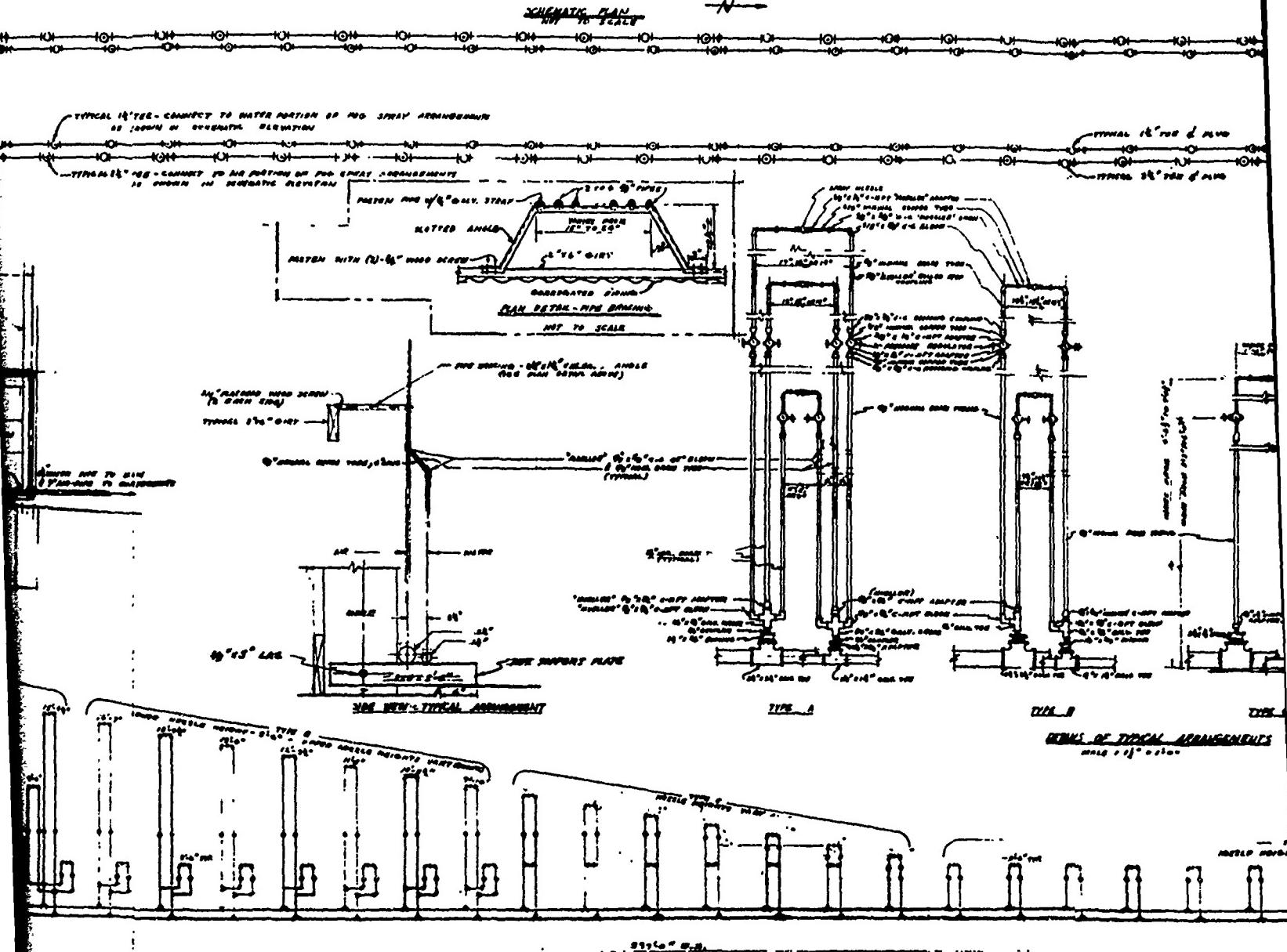


Fig. 1 - The interior of a Mercury 3000
control panel assembly.



X



NOTE: ALL MODEL OBJECTS ARE FROM FRESH CLEAR SIGHTING

SKETCHATIC ELEVATION
NOT TO SCALE

MISISON: ONE ADDITION
EACH "TYPE C" ACT
ALTERED ON JOB.

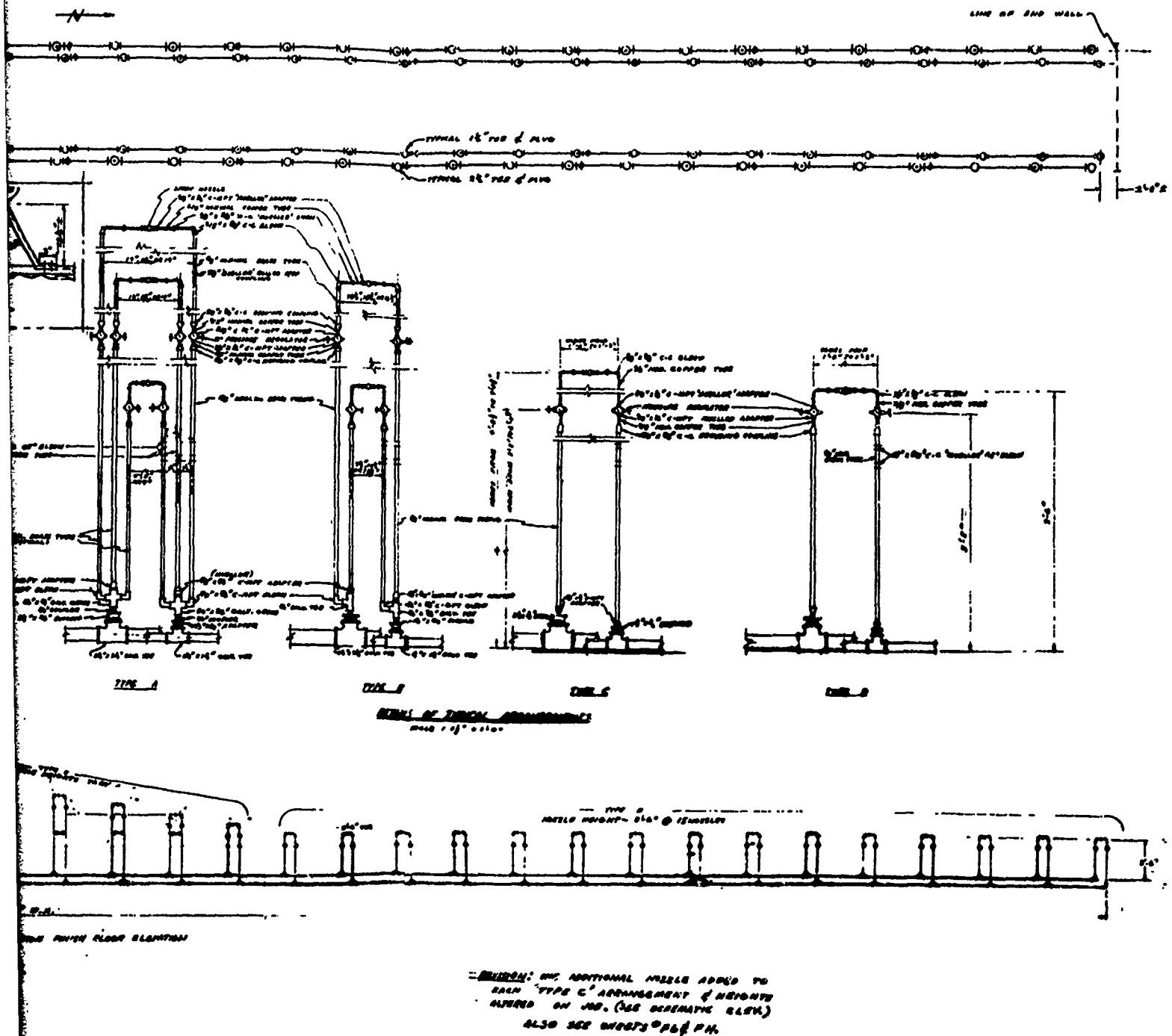


Fig. 11 - Fog generating system piping diagram.

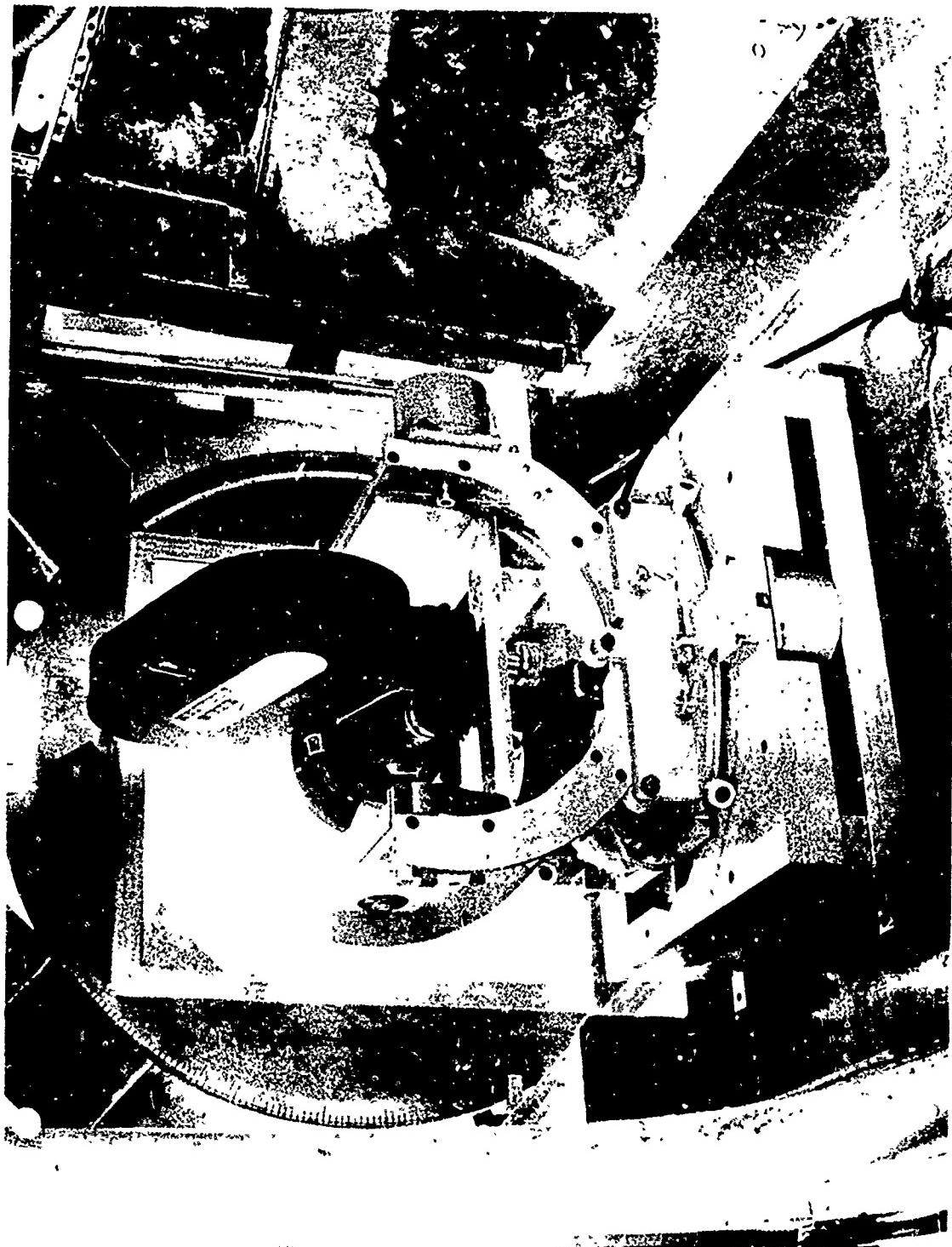


Fig. 12 - Camera Mount.



Fig. 13 - Perspective screen in place.

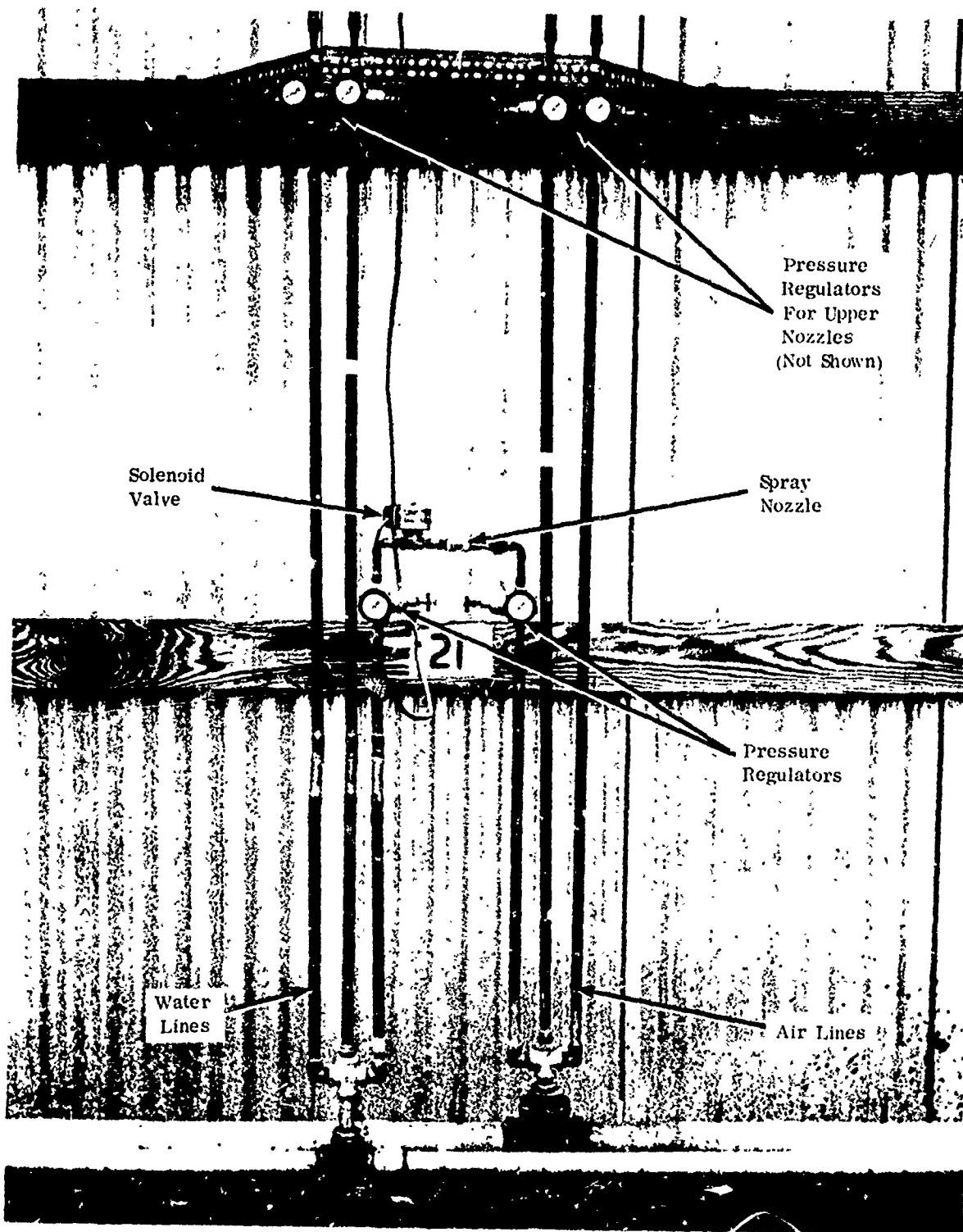


Fig. 14 - Typical nozzle manifold assembly.

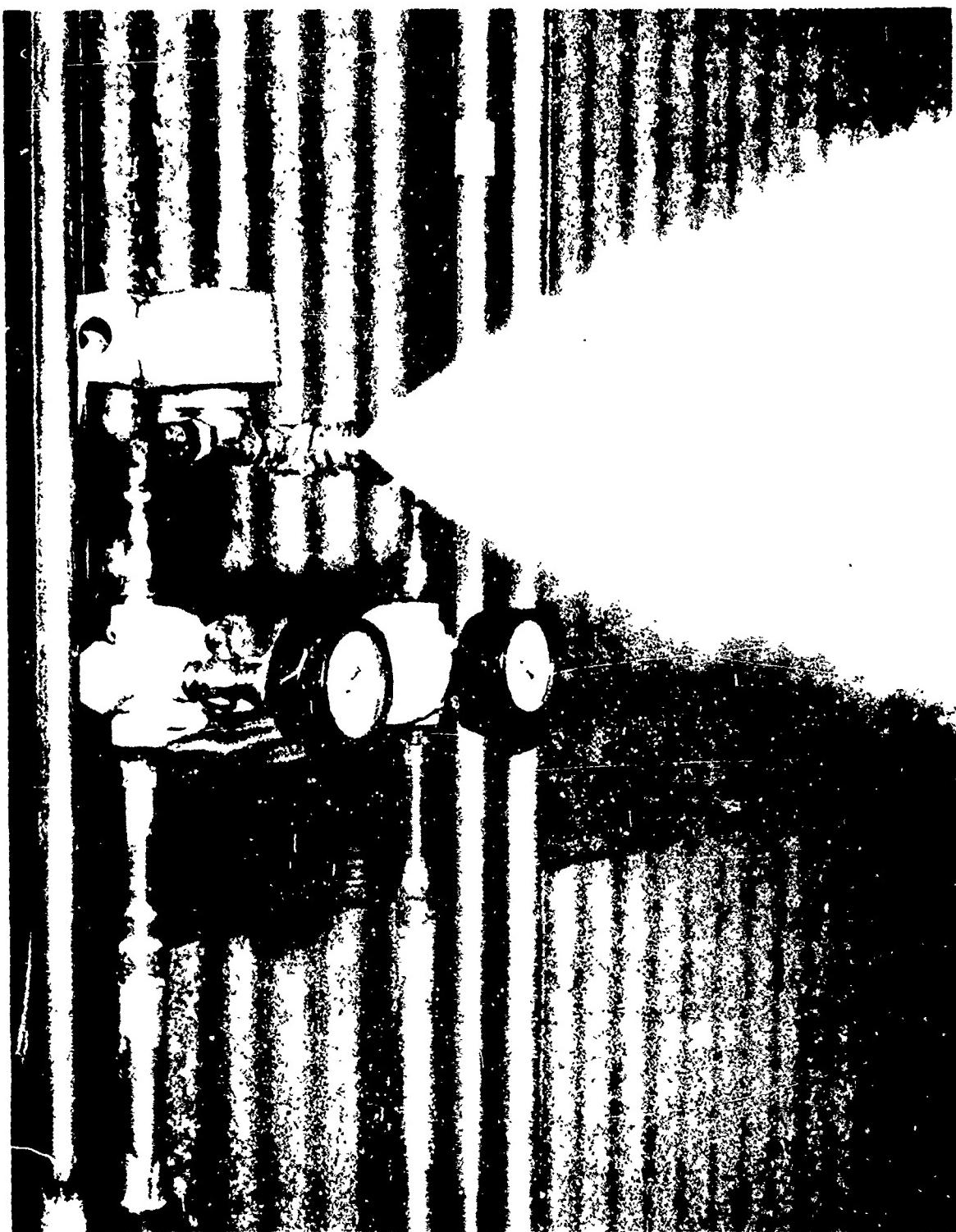


Fig. 15 - Fog spray leaving nozzle.

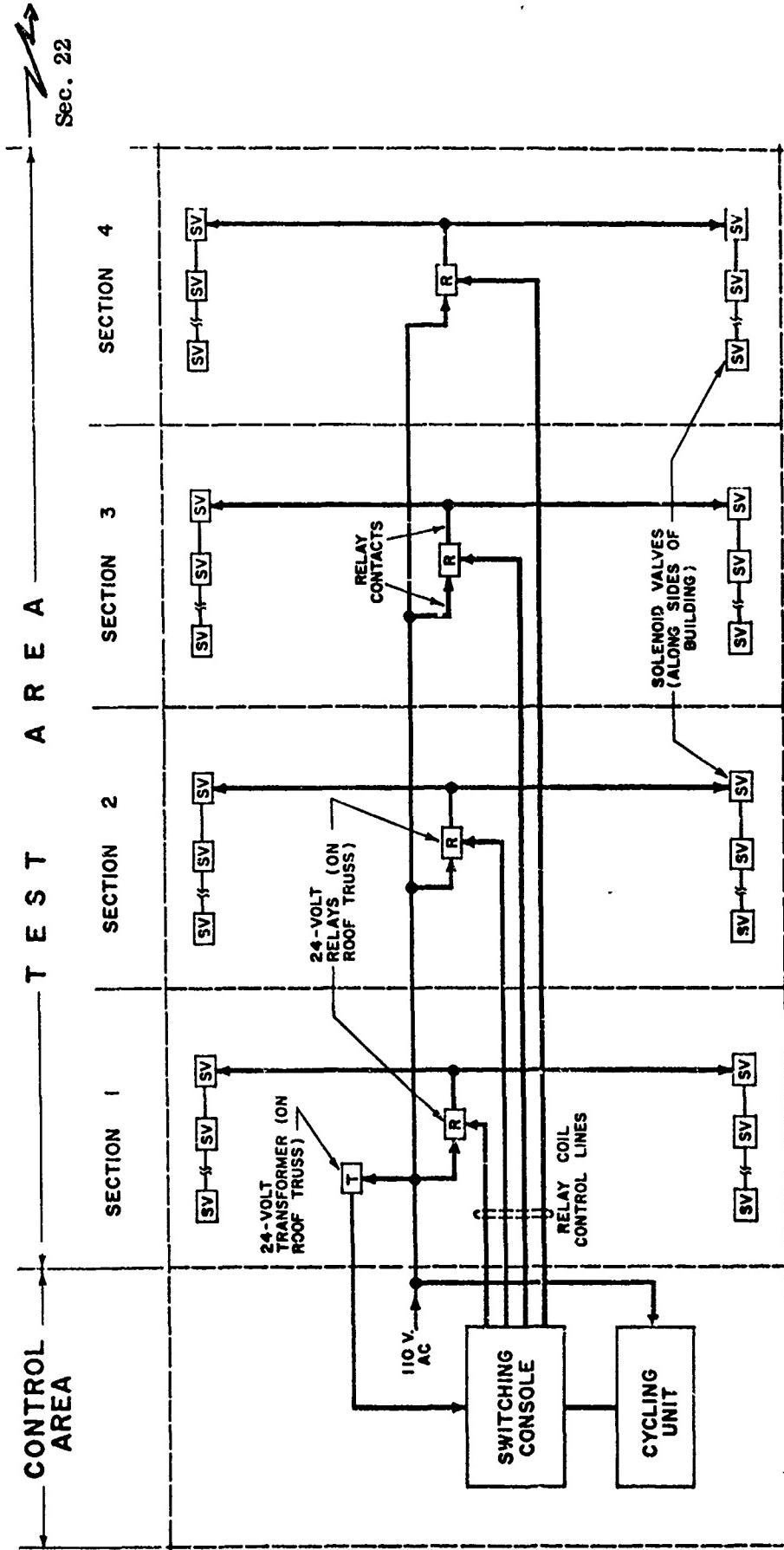


Fig. 16 - Control system layout

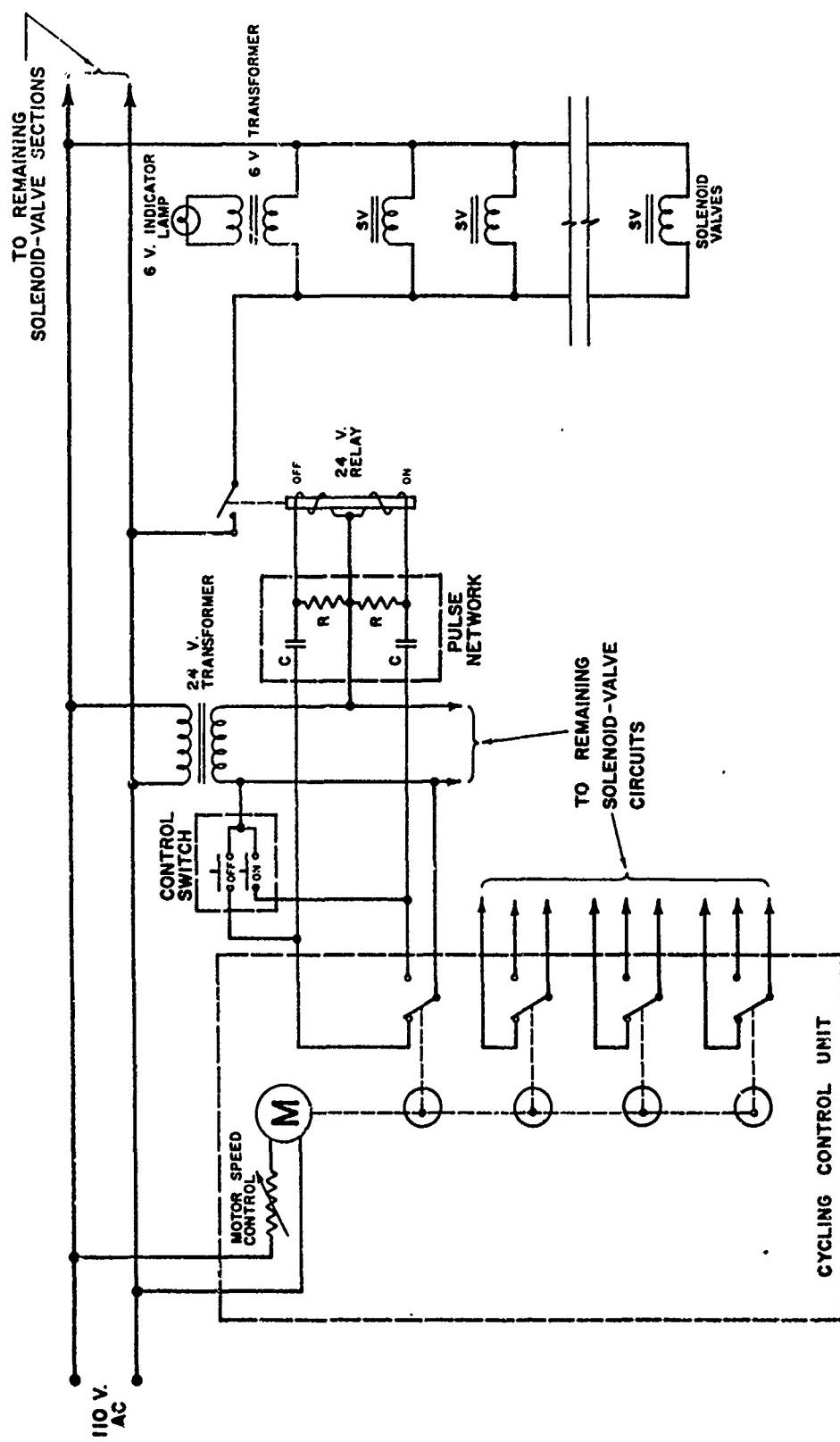


Fig. 17 - Solenoid valve control circuit.

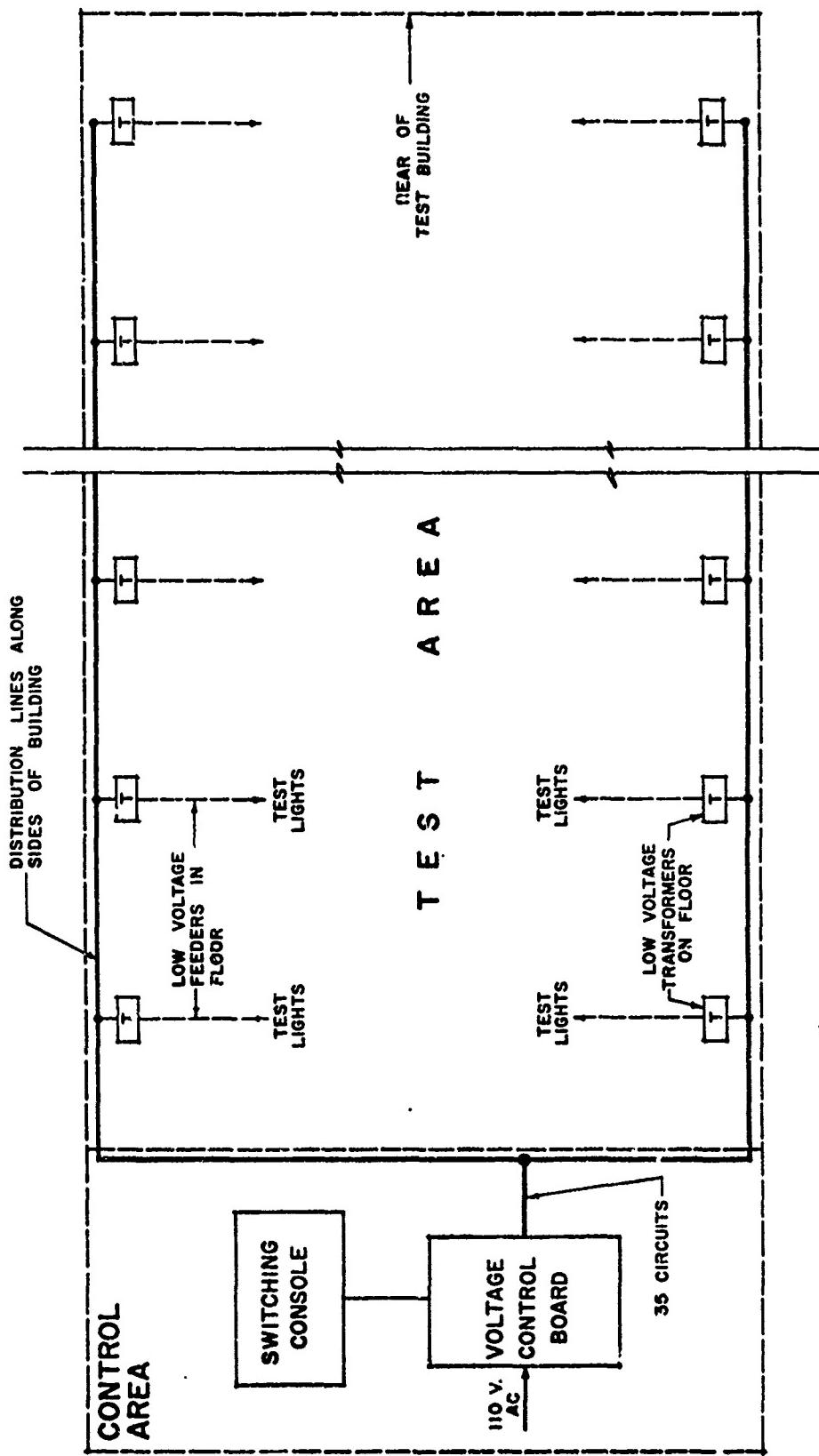


Fig. 18 - Electrical distribution system for test lights.

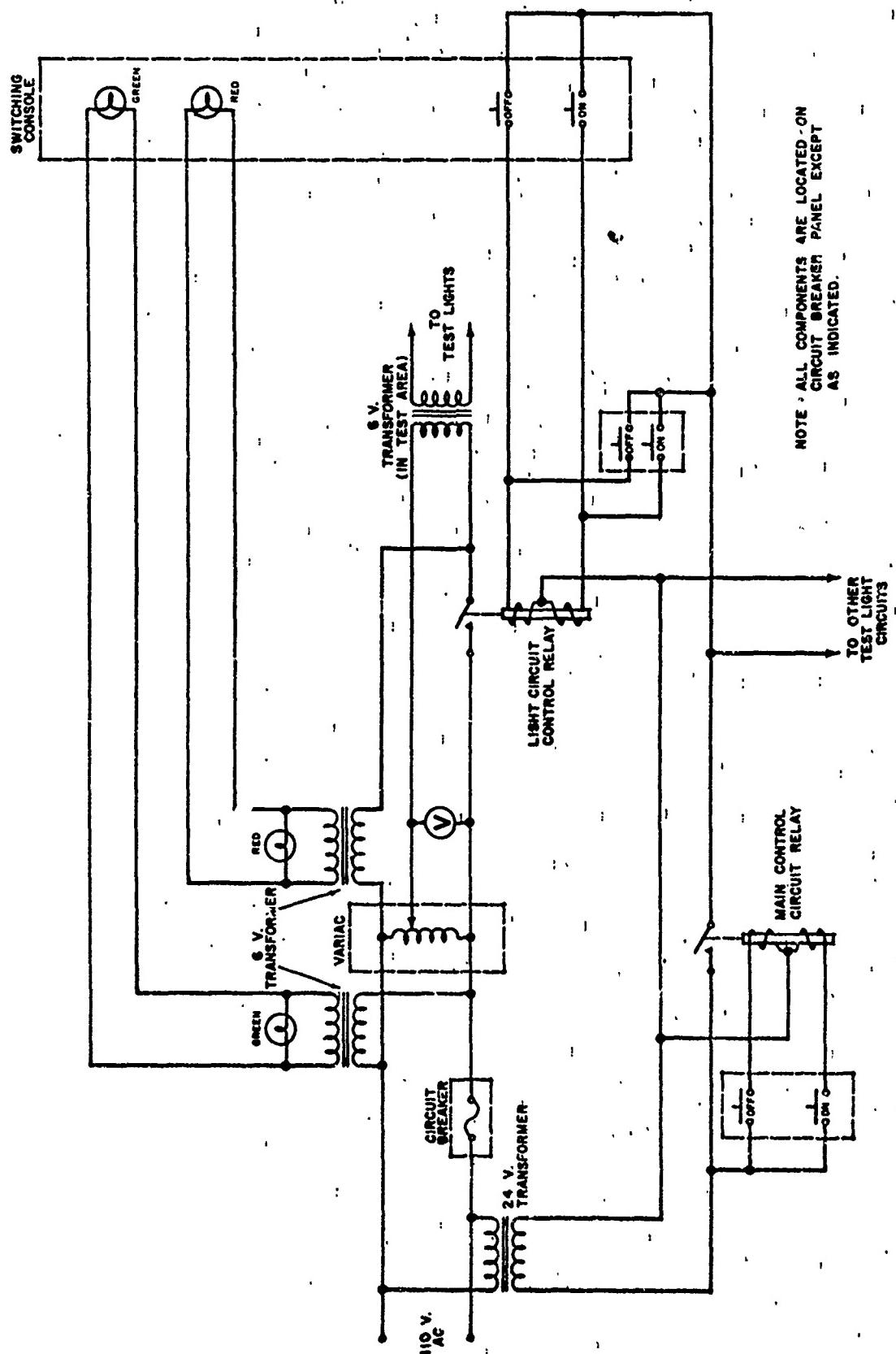


Fig. 19 - Typical test light control circuit. The main control circuit relay is common to all test light circuits.

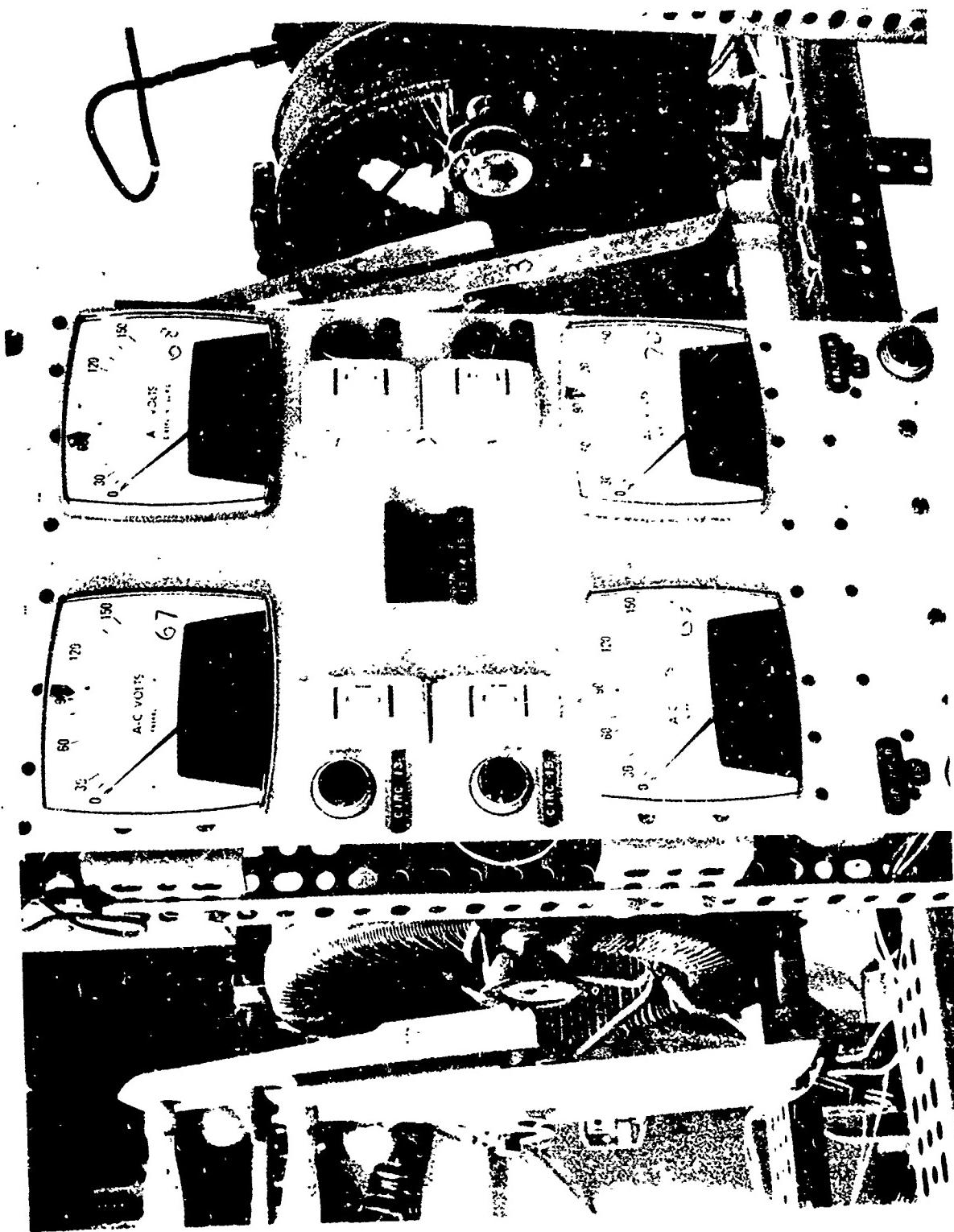


Fig. 20 - Typical circuit-breaker and voltage-control panel.

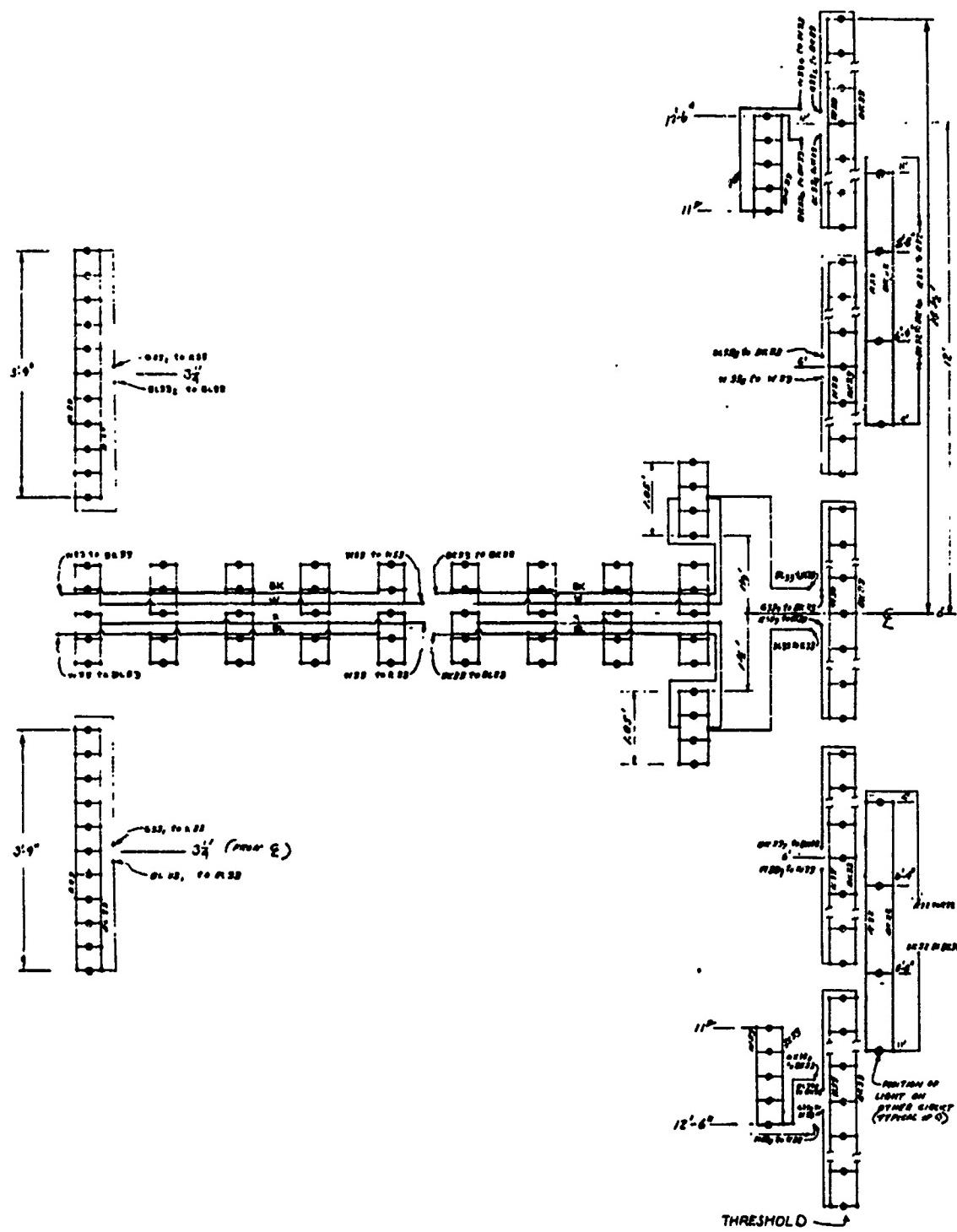


Fig. 21 - Test-light wiring diagram showing low-voltage feeder connections from 1000-foot bar to runway threshold.